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The Journal of
THE ROYAL AERONAUTICAL SOCIETY

CONTENTS OCTOBER 1951

THIRTY-NINTH WILBUR WRIGHT MEMORIAL LECTURE—
THE WELL-TEMPERED AIRCRAFT
ARTHUR E. RAYMOND

HIGH-SPEED FLYING
SQUADRON LEADER JOHN D. DERRY

POWER PLANTS FOR HIGH-SPEED AIRCRAFT
A. D. BAXTER, F.R.Ae.S., M.Eng., M.I.Mech.E.

REVIEWS

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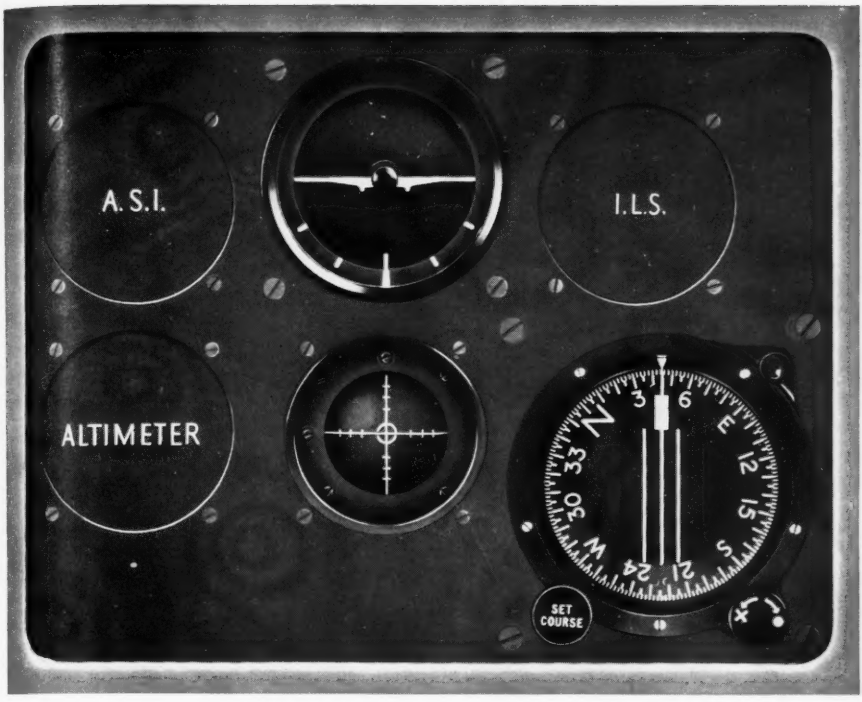

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As aircraft progress towards all-weather operation the demand for increased accuracy and improved layout of flight instrumentation becomes more insistent. Sperry's latest products to meet these demands, the Gyrosyn Compass and Electric Gyro Horizon, have now been adopted almost universally for military and civil use. These two instruments are now being joined by the Zero Reader master flight instrument, and already B.O.A.C. and B.E.A. have agreed on a standard layout for the panel of their new and future aircraft.

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AIRSPEED AMBASSADOR — *2 Centaurus Engines*

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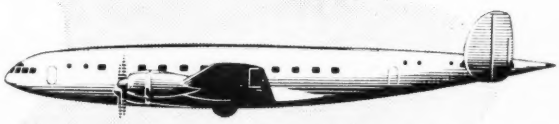

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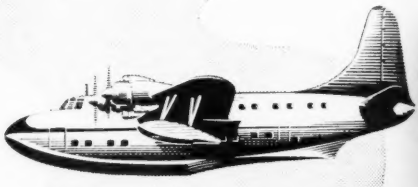
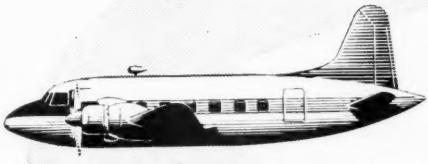


SHORT SOLENT — *4 Hercules Engines*



VICKERS VIKING — *2 Hercules Engines*

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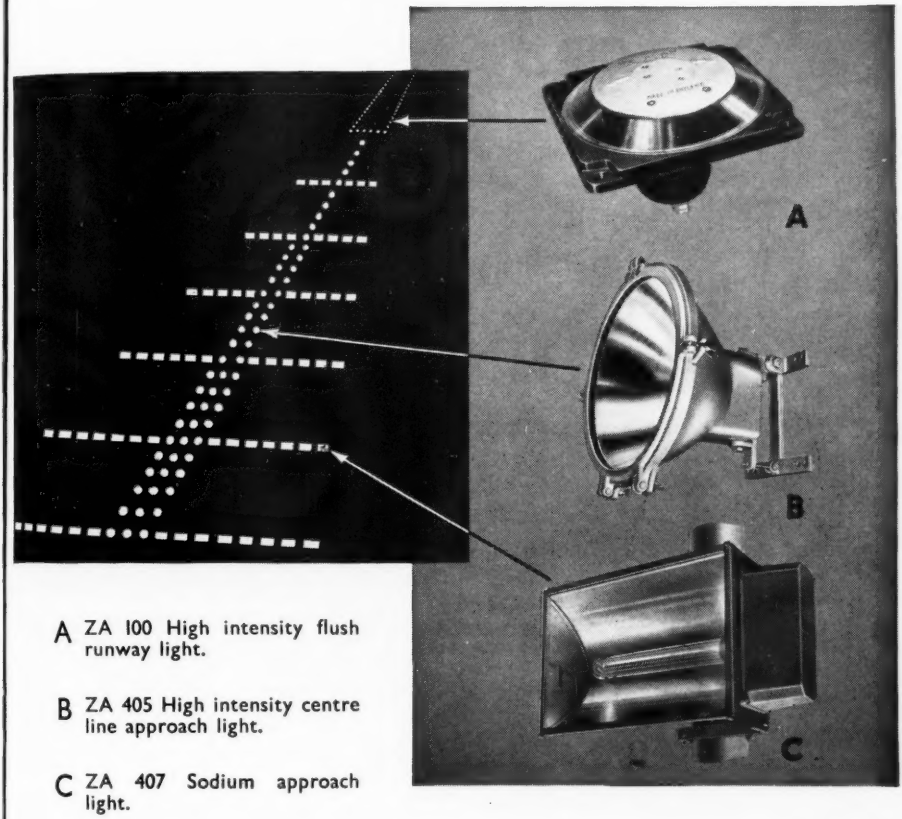

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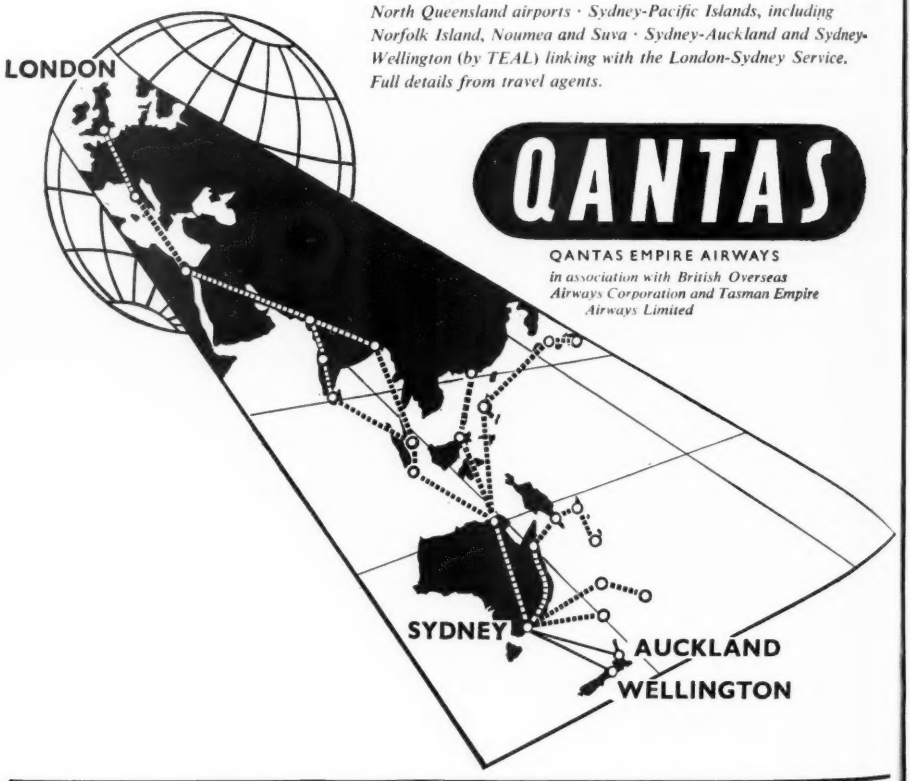

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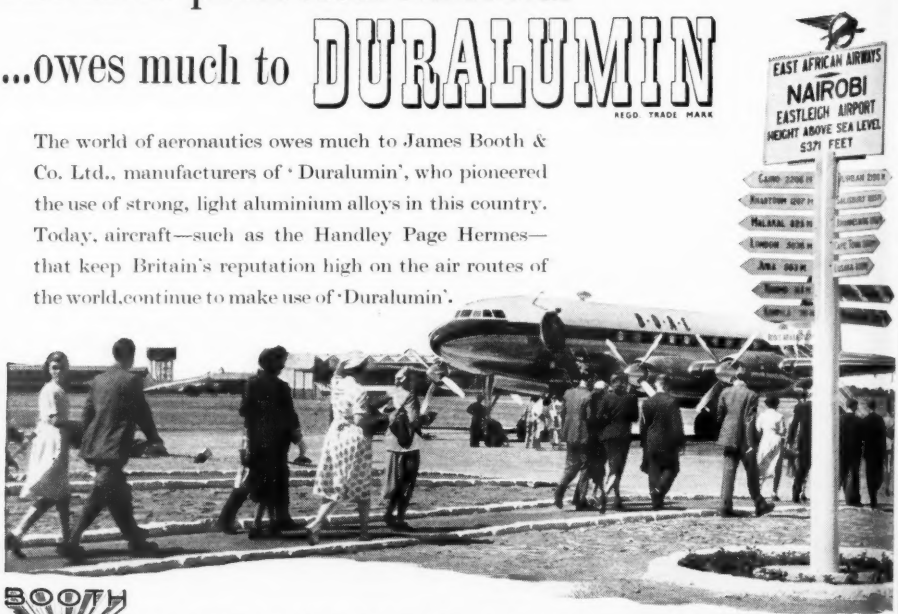

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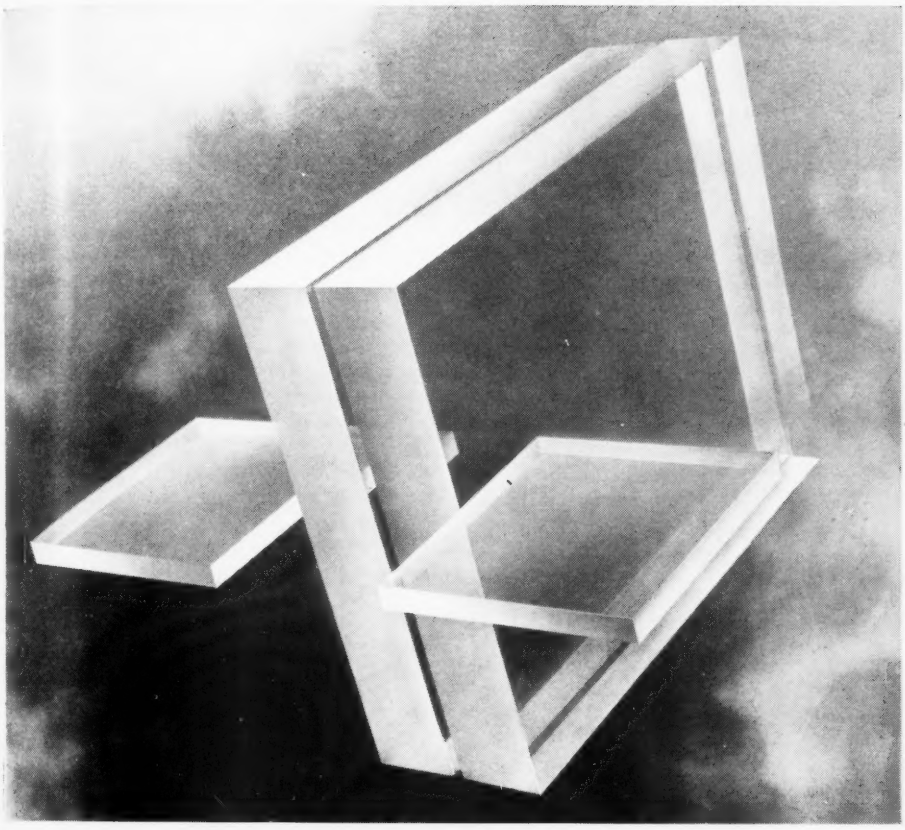

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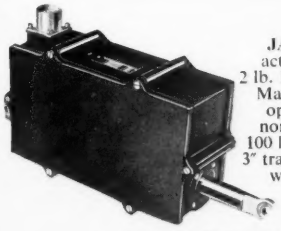

JAGUAR Linear actuator weighing 2 lb. Max. stroke 3″; Max. load 150 lb.; operating time at normal loading of 100 lb. is 7 secs. for 3″ travel. Available with various end fittings to suit particular installations. Fully tropicalised M.O.S. and A.R.B. approved.

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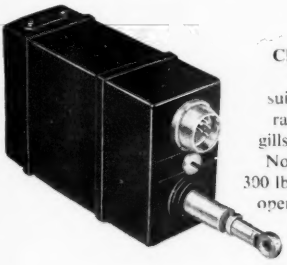
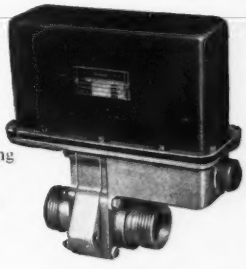


CHEETAH A more powerful actuator suitable for operating radial engine cooling gills, etc. Weighs 4 lb. Normal working load 300 lb.; max. stroke 3½″; operating time 13 secs. Current 2.25 amp. Fully tropicalised.

LYNX This fuel cock unit incorporates the Vickers-Armstrongs A1792 Mark H "P" type reciprocating action cock. Operating time 1.8 secs.; total weight 3½ lb.; current 1.1 amp. (24 v DC). Fully tropicalised.



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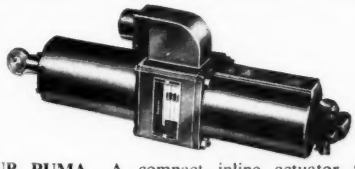

CUB PUMA A compact inline actuator for tension or compression loads. Maximum working load is 250 lb.; stroke 1″; operating time 9 secs. Weight 2¼ lb. Current consumption 1.75 Amps. Fully tropicalised. M.O.S. and A.R.B. approved.

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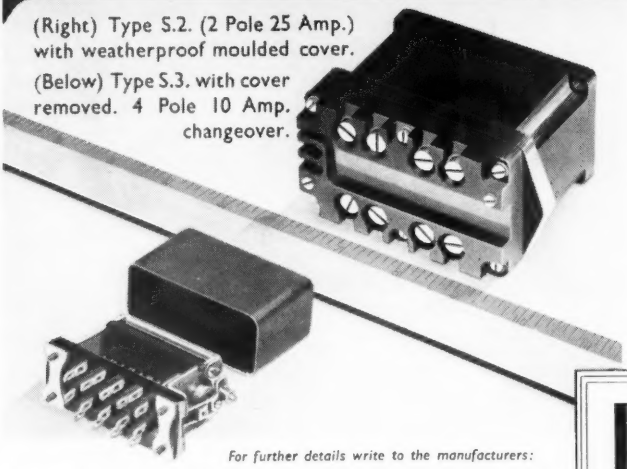
(Below) Type S.3. with cover removed. 4 Pole 10 Amp. changeover.



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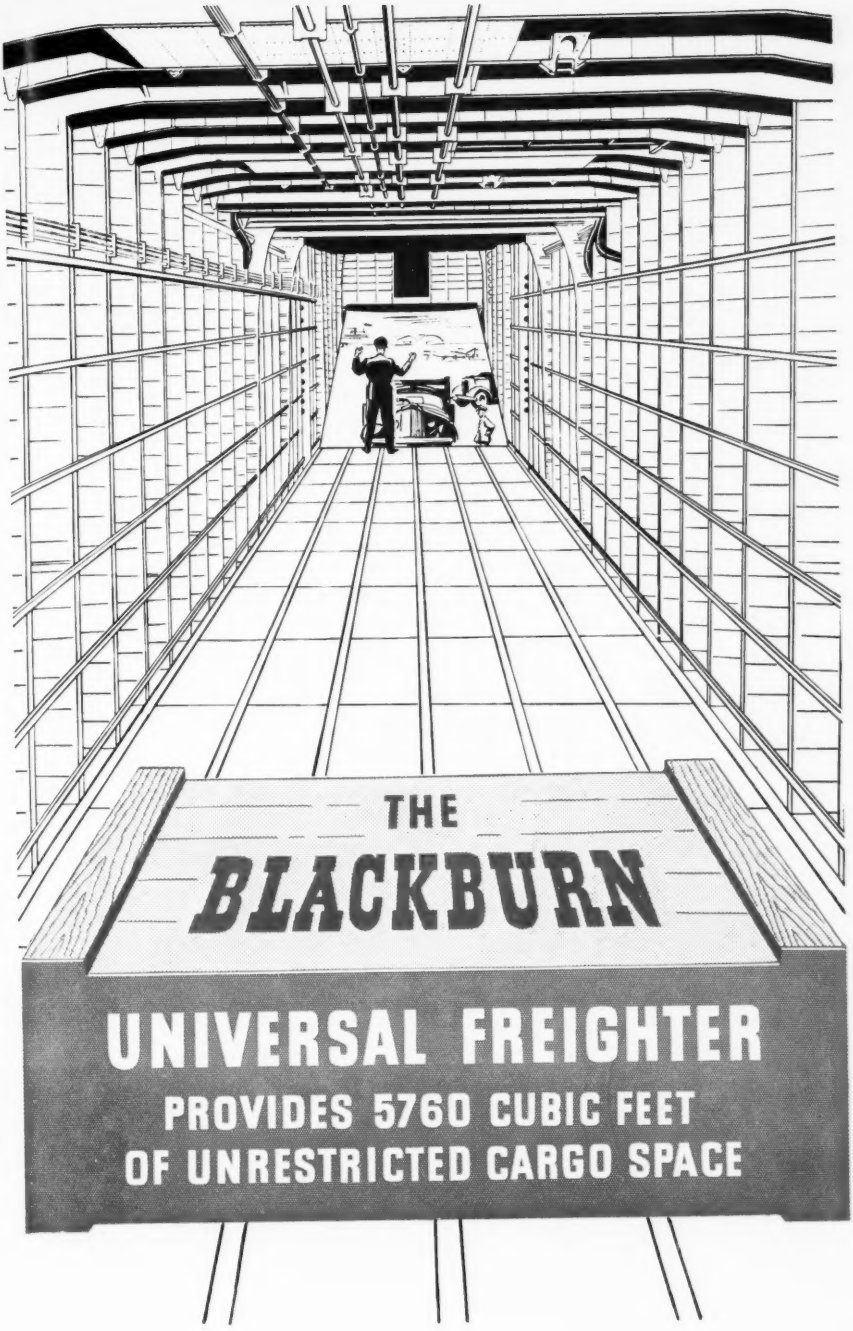
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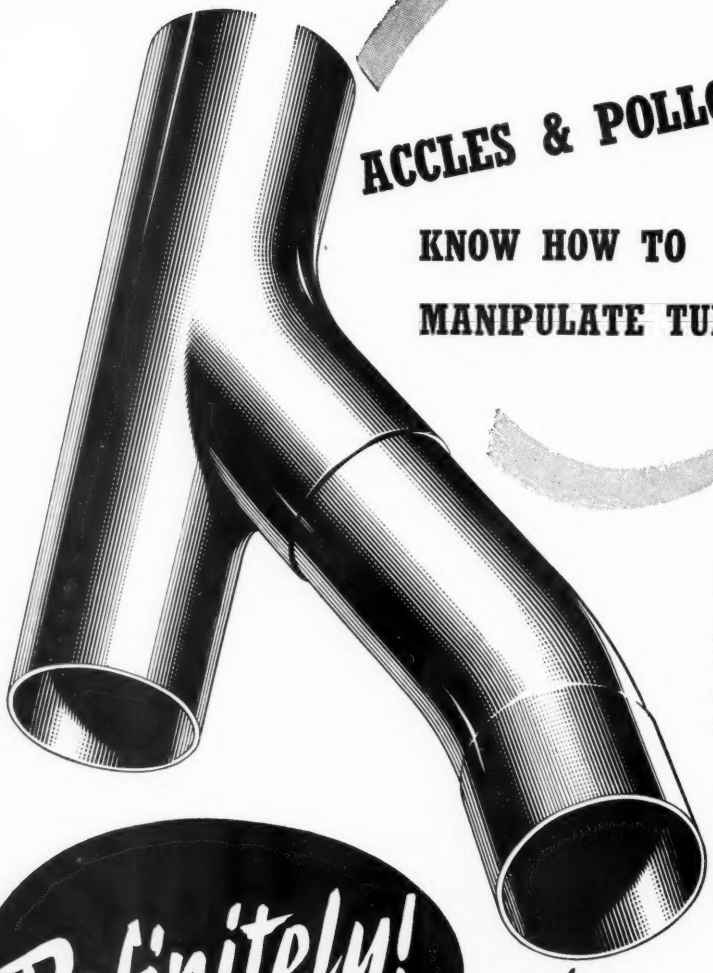

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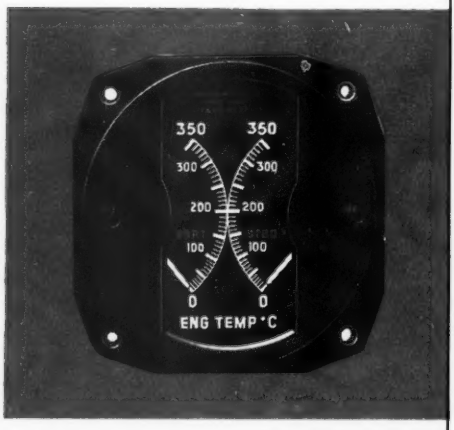

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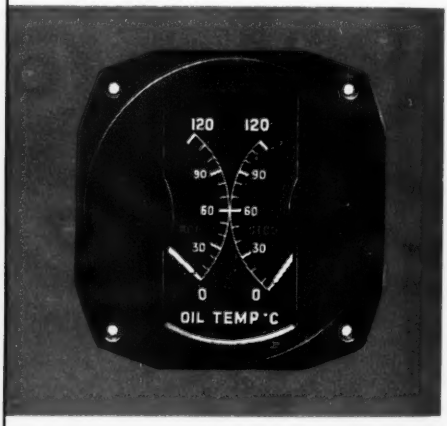

Model S 127. Dual Ratiometer Indicator, comprising two 100° ratiometer movements housed in large-size S.A.E. case. For use in conjunction with thermometer bulbs, electrical oil pressure transmitters, electrical position indicators or any combination of two of these to indicate a variety of temperatures, pressures or positions

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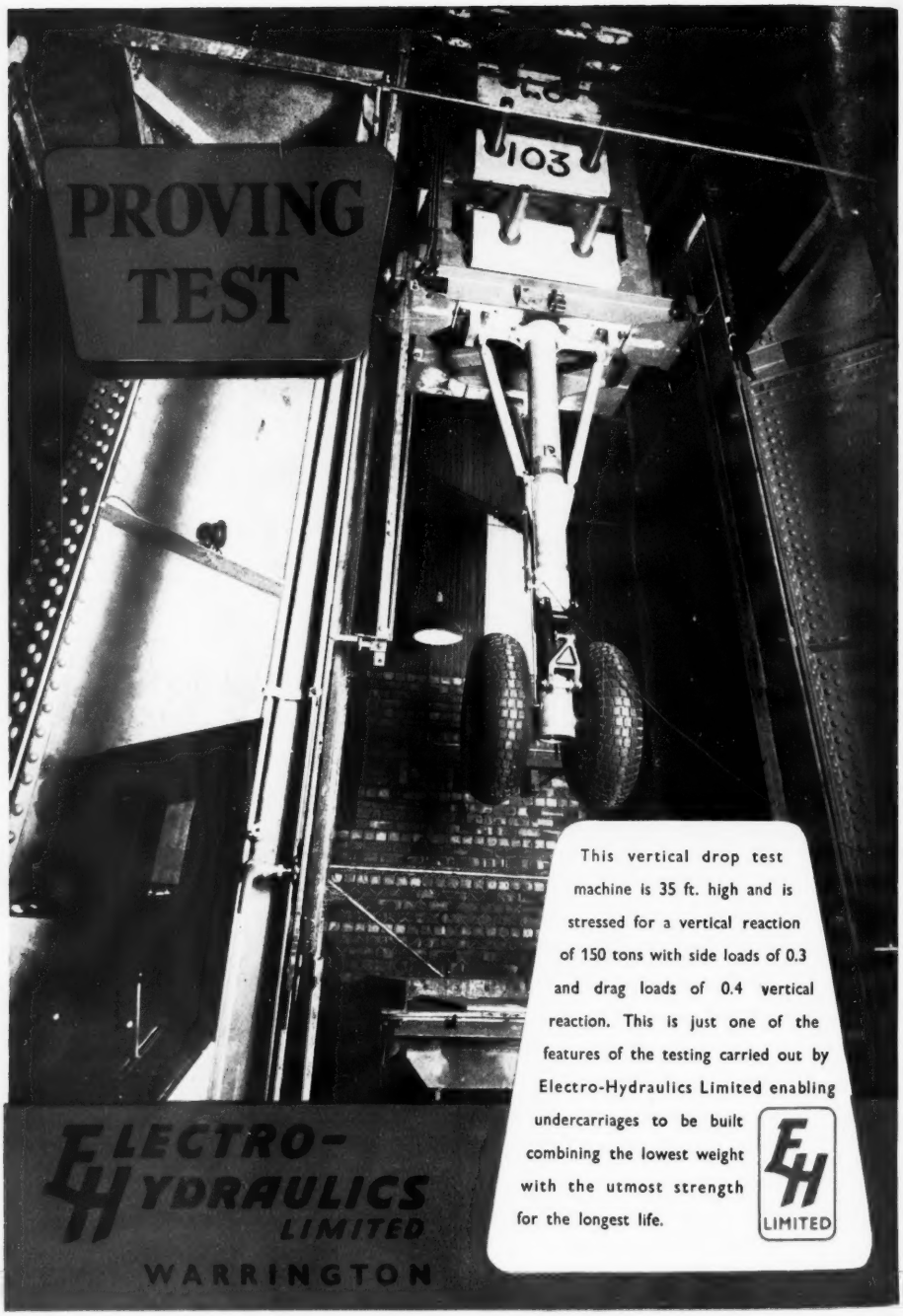
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All a matter of Hot Air?

ONE of my dictionaries—and I shall consult scores of them before this article is completed—defines jet as . . . yes, here it is . . . "*a compact, velvet-black mineral. . . .*" No, wait a minute . . . what's this? "*Jet propeller (Naut.). A device for propelling vessels by means of a jet of water ejected from the stern.*"

Well there's nothing very new in that; the squid's been jet-propelled for millions of years. D'you mean to say there's nothing in the whole dim volume about jets? Not even among the Addenda? Here, what's the date of this thing?

Very well; I shall have to make it up as I go along. Er . . . are we agreed that the gas-turbine jet engine will eventually prove at least as important to aeronautical progress as the original rotary engine, the variable-pitch constant-speed propeller, the highly supercharged engine using high-octane *Esso*, and high-tensile fatigue-resistant aluminium and other light alloys? We are? Good.

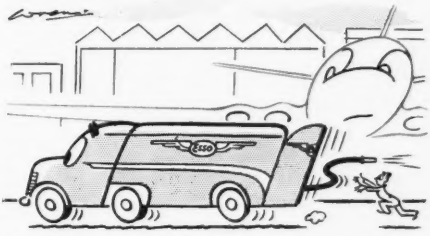
And are we agreed that a sketchy explanation of the scientific basis of jet propulsion might be that action and reaction are equal in magnitude but opposite in direction, that the force on a body is directly proportional to the rate of change of momentum of the body, or that (steady !) the propulsive thrust is proportional to the product of the mass of material ejected from the vehicle and the amount its velocity has

been increased in a given time? Excellent—let's settle for Newton's third law of motion.

"Jet propulsion" is used to cover a lot of ground and other natural elements. Rockets were used, I am told, as long ago as 1232 when they were applied to the defence of Kai-feng; at another period in history things called Buzz-bombs or Doodle-bugs were fairly common; and skyrockets have been the pyrotechnician's pride and joy ever since the invention of gunpowder.

Today there is much talk among escapists about the possibility of rocket space-ships, of interplanetary vehicles powered by liquid fuel—petrol plus liquid oxygen, say.

If, however, we are content, we little stay-at-homes, to travel *within* the earth's atmosphere we can economise by filching the oxygen needed for combustion from the air.



Now we're really getting somewhere. I've got as far as thermal-jet air engines. How about you?

For the sake of argument let's say that thermal-jet air engines include ramjets (flying stove-pipes or athodyds), gas-turbine jets, gas-turbine-with-geared-propeller-and-exhaust-jets, and supercharged-reciprocating-engine-with-geared-propeller-and-exhaust-jets. There are others, but their names are hopelessly unwieldy on this basis.

Now all of the above-mentioned engines burn fuel—not any old fuel, of course, but those specially concocted in the *Esso* laboratories. There are fuels for every type of internal combustion engine; fuels that are safe, efficient and economic; fuels that help the aircraft industry to design *better* jets; fuels given the okay for heat of combustion, freezing point, viscosity, distillation, flash point, aromatics, sulphur content, residue, accelerated gum, water tolerance and specific gravity.

No, it isn't only a matter of hot air—even though one jet, six inches in diameter, will release as much heat as several hundred oil burners.

Jets are still in their infancy—and so, let's admit it, are jet fuels. But the aircraft industry and the fuel philosophers are moving fast, getting to know the ropes and the lingo. And one very important lesson they've already learned is that . . .

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DR. A. M. BALLANTYNE took over his duties as Secretary of the Royal Aeronautical Society on 2nd July 1951. He met many members during the Third Anglo-American Aeronautical Conference in September and, as he says in the October "Secretary's News Letter," he hopes to visit all the Branches of the Society and to meet many more members during the next few months. The following brief details may help members to know something about their new Secretary.

Dr. Ballantyne is a Scotsman. Born in Glasgow, he was educated at Hutchesons' Grammar School in that city and took his B.Sc. at Glasgow University in 1930. He served an apprenticeship on the Sandwich system in civil engineering under the late W. C. Easton, Consulting Engineer of Glasgow, being engaged on Water Supply and Sewage Treatment.

In 1932 he returned to his old University as an Assistant Lecturer in Civil Engineering and Aeronautics, working with Dr. (now Professor) A. Thom, under the late Professor J. D. Cormack. He gained his Ph.D. in 1936 with a thesis on "The Prevention of Erosion at the Foot of Weirs by Sills of Various Sections." That same year he came south to University College, London, as an Assistant Lecturer in Civil and Mechanical Engineering, working under Professor G. T. R. Hill. He was appointed Lecturer in 1939.

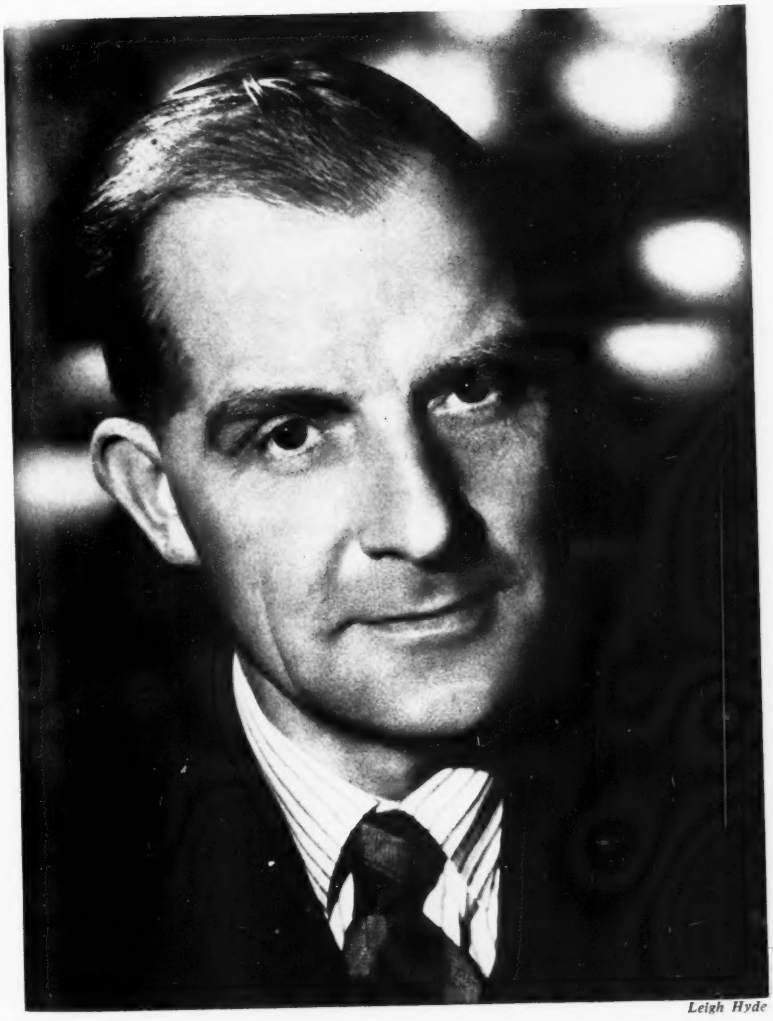
Dr. Ballantyne received his commission as a Territorial in January 1938 and was attached to the University of London O.T.C. He was called up early in 1940 and, after a period with the School of Survey, Larkhill, he instructed R.A. Cadets at the University of Glasgow until 1942. He was then attached to the Army Photographic Research Branch, School of Artillery, Larkhill.

Early in 1943 he was seconded to the Inspector General of Armaments with whom he served for the rest of the war, on fire control instruments, survey equipment and tank sighting telescopic instruments. He received his Territorial Decoration early in 1951.

Dr. Ballantyne was demobilised in October 1945 and returned to University College, London. In 1949 he was made Senior Lecturer in the Civil and Municipal Engineering Department.

Although much of his work has been in Mechanical and Civil Engineering, with hydraulics as his main interest, Dr. Ballantyne is also an aerodynamicist and has done some work on air survey. He did much flying with friends at the Scottish Flying Club, Renfrew. His main hobbies and recreations are cinéphotography, golf, sailing and writing novels. At University College before the War he was the Founder and Editor of the *Engineering Society Journal* and on his return in 1945 became Business Manager. He has written a number of technical papers. He is an Associate Member of the Institute of Civil Engineers, an Associate Member of the Institute of Structural Engineers, an Associate of the Royal Institution of Chartered Surveyors, and in 1948 was elected an Associate Fellow of the Royal Aeronautical Society.

Dr. Ballantyne is married and has two children, a daughter aged seven and a two-year old son.



Leigh Hyde

A. M. Ballantyne

Secretary.

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39th WILBUR WRIGHT MEMORIAL LECTURE

THE WELL-TEMPERED AIRCRAFT

by

ARTHUR E. RAYMOND

The Thirty-ninth Wilbur Wright Memorial Lecture, "The Well-Tempered Aircraft," was given by Mr. A. E. Raymond before the Royal Aeronautical Society on Monday 10th September 1951, at the Royal Institution, London, W.1. Major F. B. Halford, C.B.E., F.R.Ae.S., President of the Society, presided over the meeting which comprised some 400 members and guests, including Rear Admiral L. B. Richardson, President of the Institute of the Aeronautical Sciences, Mr. S. Paul Johnston, Director of the Institute, and many of the American delegates to the Third Anglo-American Aeronautical Conference.

Medals and Prizes awarded by the Council for 1951 were presented before the Lecture.

The President: Having had the honour and privilege during the previous week of presiding, together with Rear Admiral Richardson, over the Third Anglo-American Aeronautical Conference, it gave him all the greater pleasure to preside over the Thirty-ninth Wilbur Wright Memorial Lecture. This series of lectures was inaugurated in 1913 and was usually given alternately by someone from the United States and from Great Britain.

That evening they were particularly fortunate in having as the 1951 lecturer Mr. A. E. Raymond, of America. By a manipulation of the lecture calendar Mr. Raymond had an audience in which there were many more American listeners than usual. To them, on behalf of the Society, he offered a special welcome.

On that occasion he had no cable of greeting to read from the Institute of the Aeronautical Sciences, as was the custom, for the leading members of the Institute, he was happy to say, were present in person.

Not the least of his happy duties that evening was to present Medals and Prizes awarded by the Council of the Society during the past year.

The Society's Gold Medal—This was an award the presentation of which should have made the occasion a particularly pleasant one, but unfortunately it was a sad one. It was the highest honour the Society could offer for work of outstanding merit in aeronautics, and it was awarded posthumously to Mr. W. G. A. Perring, C.B., *Fellow*, for his distinguished services to aeronautical science. By his death they had suffered a great loss; indeed, it was difficult to realise how much aeronautical science in the world generally, and in Great Britain particularly, had lost. The Medal would be received by Dr. G. P. Douglas, on behalf of Mrs. Perring.

The Society's Silver Medal—for work of an outstanding nature in aeronautics, was awarded to S. B. Gates, *Fellow*, Deputy Chief Scientific Officer, Royal Aircraft Establishment, for his work on the stability and control of aircraft.

The Society's Bronze Medal—for work leading to advancement in aeronautics, was awarded to H. J. Pollard, *Fellow*, Divisional Director, Aircraft, The Bristol Aeroplane Co. Ltd., for his many contributions to the development of aircraft construction.

The British Gold Medal—for practical achievement leading to advancement in aeronautics, was awarded to A. E. Russell, *Fellow*, Director and Chief Designer, The Bristol Aeroplane Co. Ltd., in recognition of his achievements in aircraft design.

The British Silver Medal—for practical achievement leading to advancement in aeronautics, was awarded to Group-Captain John Cunningham, Chief Test Pilot, The de Havilland Aircraft Co. Ltd., for his outstanding work as a test pilot.

The George Taylor (of Australia) Gold Medal—for the most valuable paper read before the Society during the previous session, was awarded to R. E. Bishop, *Fellow*, Director, The de Havilland Aircraft Co. Ltd., for his paper on "Design for Maintenance."

The Simms Gold Medal—for the most valuable contribution read before, or received by, the Society on any subject allied to aeronautics, was awarded to Dr. G. S. Hislop, *Associate Fellow*, Senior Assistant to the Controller of Research, British European Airways, for his paper on "Clear Air Turbulence Over Europe."

The Herbert Ackroyd Stuart Memorial Prize—for the most valuable contribution read before, or received by, the Society on Applied Thermodynamics, was awarded to A. V. Cleaver, *Associate*, Special Projects Engineer, The de Havilland Engine Co. Ltd., for his paper on "Rockets and Assisted Take-off."

The Edward Busk Memorial Prize—for the most valuable contribution read before, or received by, the Society on Applied Aerodynamics, was awarded to R. Hills, *Associate Fellow*, Principal Scientific Officer, Royal Aircraft Establishment, for his paper on "The Use of Wind Tunnel Model Data in Aerodynamic Design."

The first controlled and sustained flight, 17th December 1903, Orville Wright piloting the machine; Wilbur Wright on foot.

The Orville Wright Prize—for the best contribution on some subject of a technical nature in connection with aeronautics published in "The Aeronautical Quarterly," was awarded to Dr. S. Neumark, Aerodynamics Department, Royal Aircraft Establishment, for his paper on "Critical Mach Numbers for Swept-Back Wings" ("The Aeronautical Quarterly," Volume II, Part II, August 1950).

The R. P. Alston Memorial Prize—for practical achievement associated with the flight testing of aircraft, was awarded to R. J. Falk, A. V. Roe & Co. Ltd., for his work on delta wing aircraft.

Honorary Fellowship—During the past year the Council had elected to Honorary Fellowship of the Society three men who had worked very hard for aviation, and had achieved a considerable degree of professional attainment in the field of aeronautics. They were:—

Professor Sir Melvill Jones
Sir Henry Tizard
C. C. Walker.

They would now devote their attention to the Wilbur Wright Memorial Lecture. As was customary, there would be no Discussion. Mr. Arthur E. Raymond needed no introduction to many of those present, certainly not to the Americans. He graduated with a B.Sc. at Harvard in 1920, and then spent a year at the Massachusetts Institute of Technology, where he obtained his M.Sc. In 1928 he joined the Douglas Aircraft Company, and in 1934 became Vice-President (Engineering), a position he still held.

In the aircraft field no name was better respected or admired or even known, than "Douglas," and no one had done more than Mr. Raymond to make the Douglas aircraft so deservedly renowned throughout the world. He was a Fellow of the Institute of the Aeronautical Sciences and was its President in 1946; he was also a member of the Society of Automotive Engineers, and had been a member of the National Advisory Committee of Aeronautics since 1946. He had pleasure in calling on Mr. Raymond to give the 39th Wilbur Wright Memorial Lecture.

1. INTRODUCTION

It is forty-eight years since the first powered flight at Kitty Hawk, thirty-nine years since the death of Wilbur Wright, only three since the death of Orville Wright. The entire history of aircraft design and operation lies well within the life span of many of those in aeronautics today. The particular segment considered in preparing this lecture covers a period over half the length of the total. It starts with a series of cloth-covered biplanes not too different in appearance from the one of 1903 and ends with supersonic swept-wing jet-driven monoplanes. Fig. 1 may serve to give perspective and set things in their proper time relation.

The Wright brothers undertook to design and build, simply stated, a machine that would fly. They had to design the entire aircraft including power plant and propellers. Basic research, applied research, development—all of these they had to carry out themselves. They had little to go on by way of prior knowledge and found they could not safely accept what others had written until they had themselves verified it. They had meagre financial resources and little formal engineering education. But they had a restless confidence, a talent for essentials, a healthy scepticism, and a habit of practical reasoning that is the very heart of successful design.

The Wrights built and flew their aeroplane successfully because, among other things, they saw the problem as a whole, saw its elements in proper relation to each other, gave to each the attention it deserved, and overlooked nothing. Today, although the problem of producing good and useful aircraft has become enormously more complex, the greatest success comes from the same approach. It does not pay to be too theoretical or mathematical, it does not pay to stick too closely to the drawing board, nor can individual judgment alone be relied upon. A proper combination of these and many other elements is necessary.

As the problem has become more difficult through the years, certain techniques have been devised to cope with it. Design skills have been organised and specialised. The rapidity and breadth of human calculating ability have been supplemented by automatic computing machines (*see* Appendix B). Systematic analyses have in some measure supplanted intuition. It is proposed do deal with that particular part of the "state of the art" that has to do with current principles and practices, rules and techniques, that have come to be generally associated with the design and production of well-conceived, well executed, well shaken-down—that is, *well-tempered*, aircraft.

This title has more than a passing relationship to Bach's Well-Tempered Clavichord. The physical laws of musical harmony are essentially mathematical. Two tones whose vibrations are as 1 to 2, or as 2 to 3, or as 3 to 4, are more harmonious together than mathematical laws, even when applied to a two whose vibrations are as 1 to 11, or 1 to 3.1416; but complete adherence to these device as simple as the piano, would result in an instrument with a far greater number of tones than the piano and one incredibly difficult to play. The great achievement produced by tempering, or shifting slightly, the vibrations of individual tones is that, at an insignificant sacrifice in true harmony, there results a highly practical, highly flexible instrument well within the artistic capability of ordinary humans.

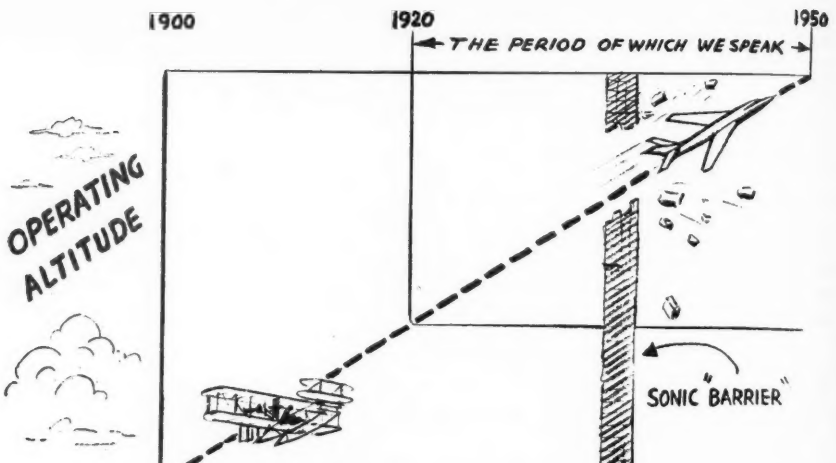


Fig. 1.

2. THE TASK TODAY

The task today in the field of aircraft design is to produce a large number of good aircraft with the least expenditure of cost and time. The resources of Great Britain and the United States are limited and must be used as effectively as possible. By *good aircraft* is meant aircraft that contribute more to society than they cost. Such aircraft normally have long production lives. They also have what might be called "design excellence," something that can only result from proper blending of accurate, impartial technical analysis with judgment and common sense, the same practical approach used by the Wright brothers forty-eight years ago.

In attacking this subject certain fundamental elements are listed. These may not be all-inclusive but they appear to be essential to the production of operationally useful aircraft (Fig. 2).

(*i*) *Proper Environment*; the work should be carried on in an atmosphere conducive to efficiency.

(*ii*) *Good Initial Choice*, based on sound specifications.

(*iii*) *Excellence of Detail Design.*

(*iv*) *Thorough Development*, the "debugging" process.

(*v*) *Follow-Through;* that is, indoctrination and assistance of operating personnel.

(*vi*) *Thorough Exploitation*; the existence of the aircraft must be made known to those who have a need for it and all the ways in which it may be used must be explored.

(*vii*) *Correct Succession*; properly timed introduction of a new model.

(*viii*) *Adaptiveness*; ability to cope with the unexpected. Since no amount of planning or technique can bring all factors under control, there must be an ability to capitalise on good luck or minimise the effects of hard luck.

These fundamental elements are now considered in turn.

3. PROPER ENVIRONMENT

3.1. Confidence

The thing above all else that makes a project go is the enthusiasm of its backers; not false enthusiasm put on for effect—sooner or later this is seen through—but rather the enthusiasm that comes from the conviction that the project is sound, worthwhile, and due to succeed. This is a point where allusion must be made again to the Wright brothers. Confidence and the courage that results from it are fundamental and essential.

3.2. Adequate financing

Confidence must be transmitted to others, and among the first who must be convinced

are those who put money into the project. Whether this backing is from the government, is private, or a combination of both, it must be adequate to carry through the inevitable times of discouragement.

It is often easier to build a prototype than it is to put it into production. There are many reasons for this but one of the most important is that the aircraft can never be proved a success until its development period is behind it, or until several machines have been in operation for some time. On the other hand, until its success has been reasonably established, it is difficult to get people to buy it. There is an interdependence between sales and aircraft-in-being that makes it difficult to have one without the other. As Mr. G. R. Edwards has so aptly said, "A wavering customer is often comforted by a piece of ironmongery—it helps him to make up his mind."*

It so happens, also, that the greatest need for funds tends to come at the time when troubles are most likely, that is, the early production period. This is shown on Fig. 3.

*Problems in the Development of a New Aeroplane. G. R. EDWARDS. *Journal of the Royal Aeronautical Society*, March 1949.

FUNDAMENTAL ELEMENTS

1. PROPER ENVIRONMENT.
2. GOOD INITIAL CHOICE.
3. EXCELLENCE OF DETAIL DESIGN.
4. THOROUGH DEVELOPMENT.
5. FOLLOW-THROUGH.
6. THOROUGH EXPLOITATION.
7. CORRECT SUCCESSION.
8. ADAPTIVENESS.

Fig. 2.

3.3. FACILITIES

Many a successful aircraft was built under great physical handicaps and it certainly cannot be proved that good working conditions are imperative. The human spirit often triumphs over obstacles but that fact is not necessarily a good excuse for having them. On the whole, more efficient work will

FINANCING CONSIDERATIONS

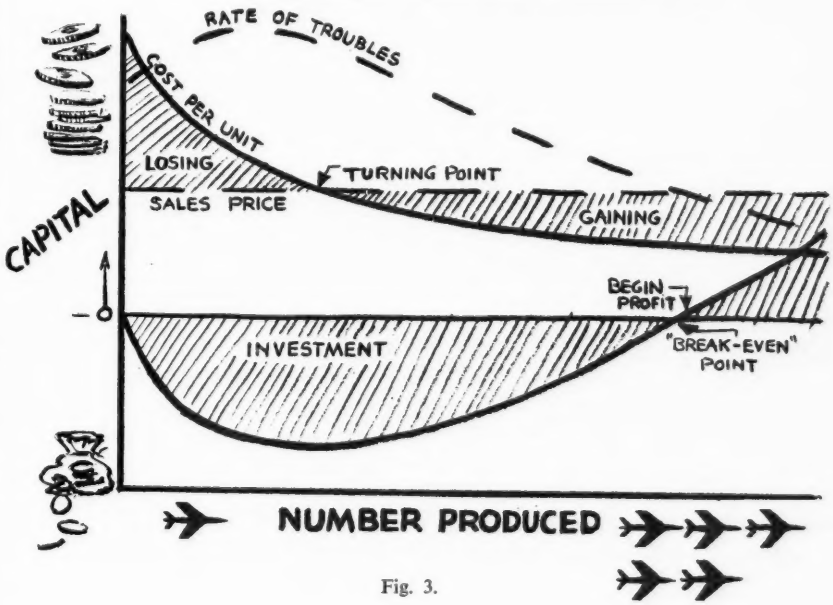


Fig. 3.

certainly be done if factory and drawing office layout is right, if there is adequate space per man, and if the lighting, temperature control, ventilation, and freedom from noise or distraction, meet certain standards. The design area should also be close to the loft, the test laboratories, the mock-up, and the experimental manufacturing area.

3.4. Organisation

The supply of properly trained and experienced personnel is not enough to meet the demand; the work of every man must be made to count to maximum degree. Given a certain selection of available individuals, two factors of organisation which affect output are the attitude and spirit of the workers and the formal relationship between them, the so-called organisation chart. Again, spirit counts for so much that it often prevails over poor organisation form, but why force it to do so?

In the design organisation—and the same thing holds true elsewhere—two types of co-ordination must be provided for, co-ordination by specialty and co-ordination by project (Fig. 4). Heated arguments have been held as to whether a specialty or group system is better or worse than a project system, but it seems to make little difference which is used; they will both work. The important thing is that one or the other form of co-ordination be given preference when it comes to administrative authority and that it be clearly understood by everyone where this preference lies. No man can serve two masters.

On the other hand, he *can* do so if they are his masters for two sufficiently separate or different things. For example, a form of organisation has been tried with success in which some supervisors are given two assistants, each with line authority. The chief engineer may have an administrative assistant and a design assistant, each supreme over the drawing office in his particular field. Or a specialty head may have a research assistant and a production assistant.

Concurrent with the great elaboration of aircraft design has come a narrowing of the horizons of many of the designers. It is usually impossible to maintain the same conditions as used to apply twenty or more years ago, when a man was thoroughly versed in one field and competent in many others, and when the designer often did his own stress analysis and weight estimation and followed his design intimately through all phases of manufacture and test. This narrowing takes away much of the feeling of identity between a man and his work—the day of the specialist is here, perhaps even more in the United States than in Great Britain. But if it is believed to be important to keep universality alive, much can be done towards that end. Certain men can be given more general

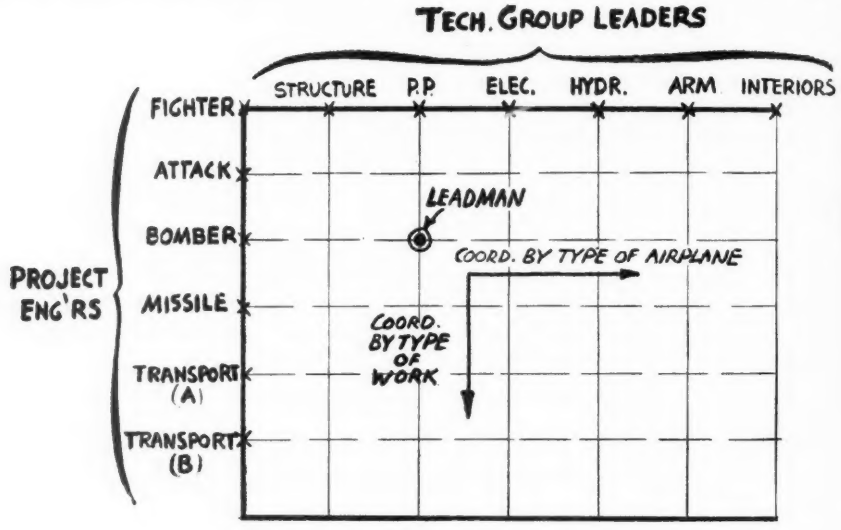


Fig. 4.

assignments, others can be moved about from time to time, and a greater opportunity can be afforded to designers to see for themselves the products of their brain in operation.

Everything possible should be done also to ensure that the engineer and designer on the one hand, and those who will manufacture and use the aircraft on the other, understand and consider each other's viewpoint.

3.5. Relations with the customer

The contract and the aircraft specification, constituting the written agreement between producer and user, can be of assistance in clarifying the role of each and setting forth what is to be done, or they can be a straitjacket within which constructive movement is almost impossible—it all depends on how they are written. Attempts to define everything and to provide for every eventuality are bound to fail, but oral agreements are equally unworkable; clear and simple understandings must be the objective with a reasonable degree of leeway for detail compromise as the project goes along. Where large organisations, such as the government and military services, are involved, things tend to become stereotyped and the individual cannot do much, but often improvements can be made by combining forces and going after them in concert.

The written word must be supplemented by many personal contacts. These fall into two categories, both of them subject to abuse, but both very helpful if used properly. The first of these is what might be called *concurrent liaison*, the joint focusing upon design problems, as they occur, of the viewpoints of manufacturer and operator, and of sub-groups within the sphere of each. The second, or *liaison after-the-fact*, is the inspection and acceptance process. The first tends to prevent mistakes and the second to correct such as inevitably occur.

These are what seem to be chief among the environmental factors. In sum-total they do much to determine the atmosphere in which a project is carried out and its chances of success. Through them all runs the common thread of joint dedication to a common task, which cannot possibly come about unless those engaged in the task believe in it, love it, and have, as already said, a justified confidence in it.

4. GOOD INITIAL CHOICE

A few years ago there was a moving picture which used to be introduced at otherwise dull technical sessions in the United States to liven up the proceedings. It was called "Design Oddities" and was a compilation of newsreel shots of aircraft of unusual appearance that had gathered in the files over a number of years. There were square wings, circular wings, wings like a doughnut with a hole in the centre, multi-cellular wings, bat wings, and so on. Looking at this picture was encouraging, for it was visual proof of the old adage that even a kitchen stove could be made to fly if it had enough power (Fig. 5). But these were inventor's aircraft—museum pieces—and none of them had any future but to amuse. There was a tendency to ask, "Why in the world did that fellow ever start to build that in the first place? What made him think it was a good idea?"

These are extreme cases, but all those who have any considerable experience in aircraft design can look back over the years and find examples for which they were responsible which raise the same questions. The only answer is that it did seem a good idea to someone at the time. Someone in government or from within the military or civil operators or in industry became convinced that there was a need for such a machine. He marshalled a few arguments, convinced someone else, and the ball was rolling. As it gathered momentum, arguments in favour were high-lighted, arguments against were stepped on, personal pride became involved, people became committed, and sober analysis of pros and cons became impossible. The project went ahead, the aircraft was designed, built, and flown—usually rather successfully—and then what happened? Nothing. Because nobody really wanted it, or because the wanters wanted something else more. Obviously a project will be doomed from the start if it does not fill a real need.

There are two sides to this question of deciding what to build; one is *what is needed*, the other is *what is possible*—what *should* be built versus what *can* be built. These have to be considered separately and in relation to each other if the choice is to be a good one. The establishment of a sound realistic set of military requirements, for example, is a high art demanding the pooling of experience, analytical skill, and judgment of people with widely varying background. The kind of fighter needed five years from now depends not only upon the materials, engines, radar, and armament that will be available by that time, but also upon the characteristics of

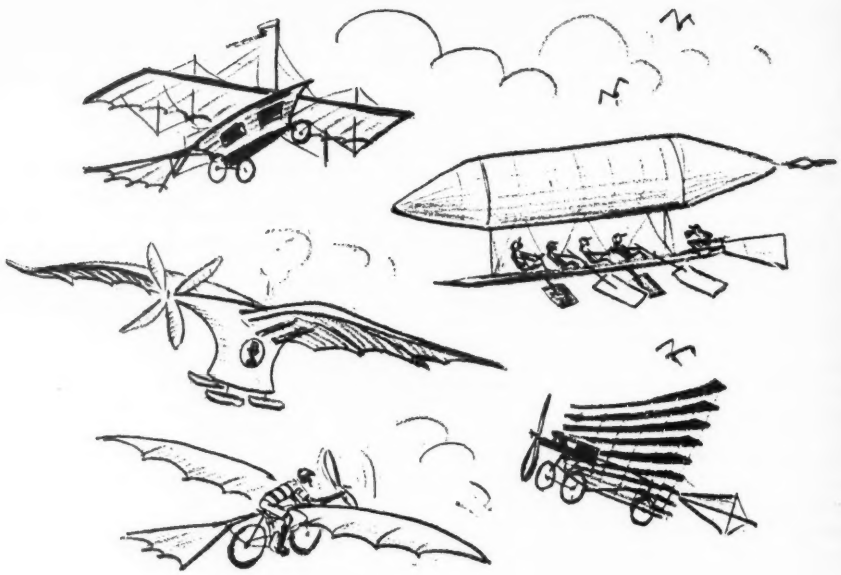


Fig. 5.

enemy bombers and fighters then, and the tactics they will employ. It depends, moreover, on the amount of money which can be spent on fighters in relation to what is spent on other things. It depends on how good other methods of defence, such as missiles, will be by that time. In other words, it depends not only upon the fighter itself but upon the whole defence system of which the fighter is a part. The same can be said of any other military aircraft.

Consequently, in recent years there has grown up a technique of initial choice which has come to be termed "Systems Analysis"; the aim is to study analytically and as a whole the military task to be performed, integrate the aircraft into that task, and establish the major characteristics of the aircraft that will best do the job. The great danger of Systems Analysis is that it may be taken as a complete substitute for the exercise of intuitive judgment. No matter how accurately or extensively a mathematical analysis is done, its conclusions can be no better than its original assumptions. The great value of Systems Analysis lies in the fact that it reduces some of the elements of the problem to precise terms and thereby makes the rest more manageable by the processes of expert opinion. As time goes on, experience with this technique will improve and extend it, as was the case with Operations Analysis during the Second World War. Meanwhile, it should be taken for what it is, a useful tool.

That part of the problem of initial choice which has to do with determining what is technically feasible, is often called "Limitations Analysis." One of its end points is a graph on which is plotted, against gross weight and wing area, a series of curves of various constant performance characteristics. There results a shaded area which defines the combinations of gross weight and wing area, for a given aircraft configuration, that have performances better than certain prescribed values. A sample of one of these graphs is shown on Fig. 6. They may be prepared for several configurations and thus may assist in choosing between them. Sometimes it is found that the proposed minimum performances have been set too high, in which case there is no shaded area at all. Assuming there is one, discrete values of wing area and gross weight are usually chosen with an eye to the possibilities they present for future growth of the design.

Limitations Analysis is really a partial definition of what is commonly called "the state of the art," the level reached by the constantly rising progress curve. An aircraft designed in such a way as not to take

reasonable advantage of the state of the art is handicapped competitively; one designed too far in advance of it, with too much optimistic anticipation, runs into the dangers inherent in all pioneering efforts.

Aircraft design has progressed in a series of pioneering jumps, combined with a large number of relatively unspectacular evolutionary improvements. Certainly the Wright brothers pioneered. So did many others to whom a great deal is owed. At the same time it must be admitted that the pioneer has not always been successful in producing large quantities of operationally useful aircraft. He often has to concentrate so hard on the problem of doing the job at all that he is not able to do it as well as he himself might on a second attempt—or as someone else who has been watching his struggles may do before the pioneer has had time to recover his physical and financial strength.

This does not necessarily mean that design should not be in advance of the state of the art but it does indicate the importance of keeping one's eyes open to the resulting dangers. If, instead of aiming too high, a conservative approach is adopted, a number of advantages become immediately apparent. Experience with past designs can be carried over into the new one with little or no change. The assurance of having a design which will require little development often makes it possible to start production before the prototype has been tested, thus shortening the elapsed time before the aircraft comes into the market. With civil transport aircraft, near conventionality makes passenger acceptance more sure and makes operators more willing to order while the aircraft is in the blueprint stage—and the manufacturer more willing to accept such orders. All of these things make it appear more attractive to do what has been done before but in a slightly different way, rather than to branch out into something new. On the other hand, such an attitude carried to extremes stifles progress and, since there are many adventurous spirits in this business and always will be, it leads to being over-run. On the whole, "carry-over" has such a great effect on aircraft cost that it must be retained as a nucleus around which a few pioneering electrons revolve (Fig. 7).

Doubling the number of aircraft produced cuts their unit cost by about twenty per cent. Since versatility extends the market and

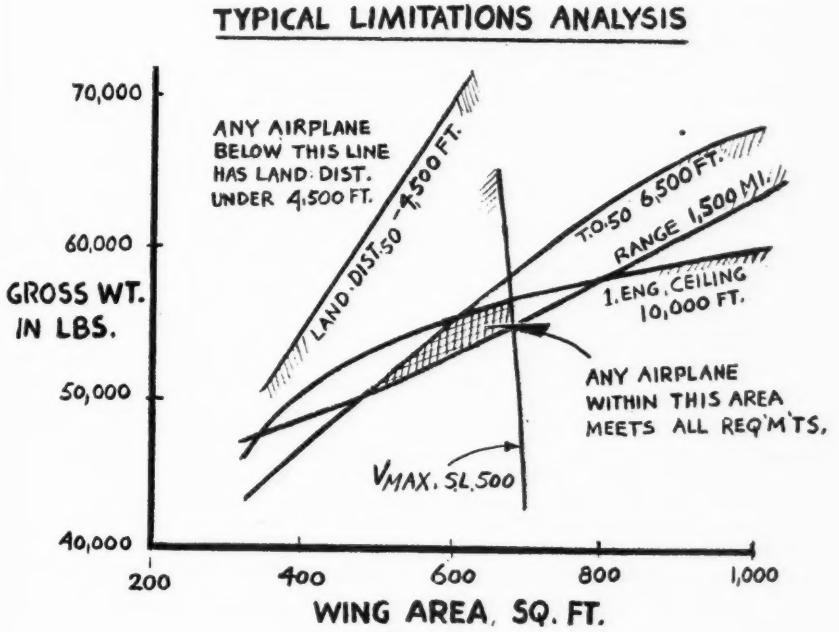


Fig. 6.

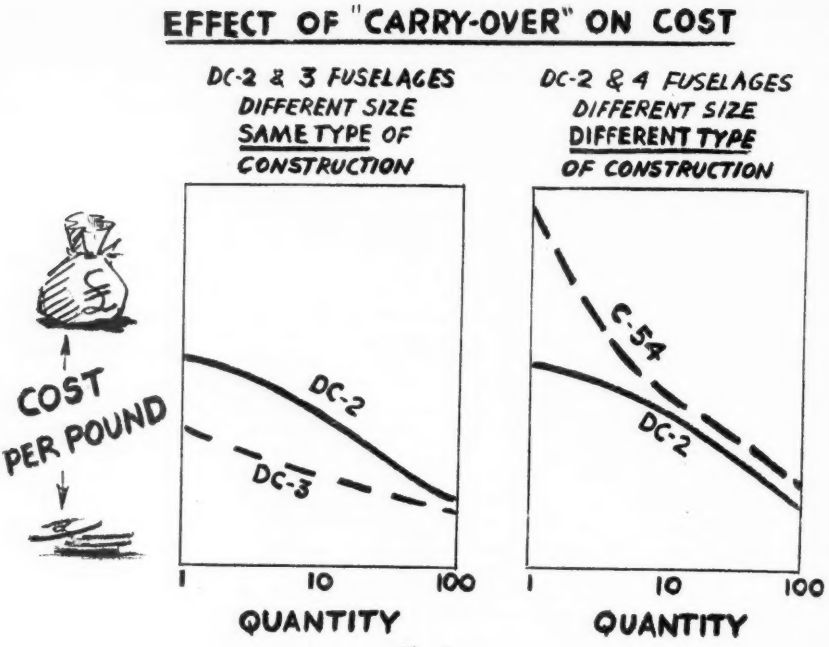


Fig. 7.

makes a given budget go farther, there is a continual temptation to combine two or more requirements into one multi-purpose design. If the requirements are sufficiently similar this can be done satisfactorily; if they are too far apart, the result is a product which really satisfies no one. Particularly is it true of civil transports that unless the market is extensive, the unit cost will be too high to be borne; too great a degree of specialisation cannot be supported.

The designer has to ask himself several rather searching questions before reaching a final decision to go ahead with a project. Not only does he have to assure himself that there is a *bona fide* need for the kind of aircraft he can produce, but he has to ask, "Is there any alternate aircraft already in existence that might be more cheaply and easily modified to meet this requirement and will my new design be sufficiently superior to justify itself? What is my competitor doing? Is he so entrenched that it will be extremely difficult, if not impossible, to make headway against him? On the other hand, has he been established in the field so long that he is perhaps growing complacent? Should he have brought out a new model some time ago and failed to do so, thus giving me an opening?"

The designer also has to make a careful assessment of the availability, by the time he needs them, of adequately developed engines, propellers (if any), and other equipment. There is a place for gliders, but only for gliders that were designed as such from the start. Designing and building an aircraft in these days of specialisation is much like cooking a party dinner: everything must be ready to come off the stove at the same time.

A sound choice is made more difficult because of the element of forecasting or prophecy that enters into it. It is important to look forward to the day, perhaps four or five years ahead, when the proposed aircraft can actually be in service in large numbers and to try to foresee what kind of aeroplane will actually be needed *at that time*. It is possible to cite many instances where insufficient attention to this element of prophecy (perhaps merely an unimaginative adherence to current thinking) has resulted in an abortive product. It is equally possible to cite cases where a particularly clever reading of the future, due to unusual awareness of what is going on at the grass roots, has

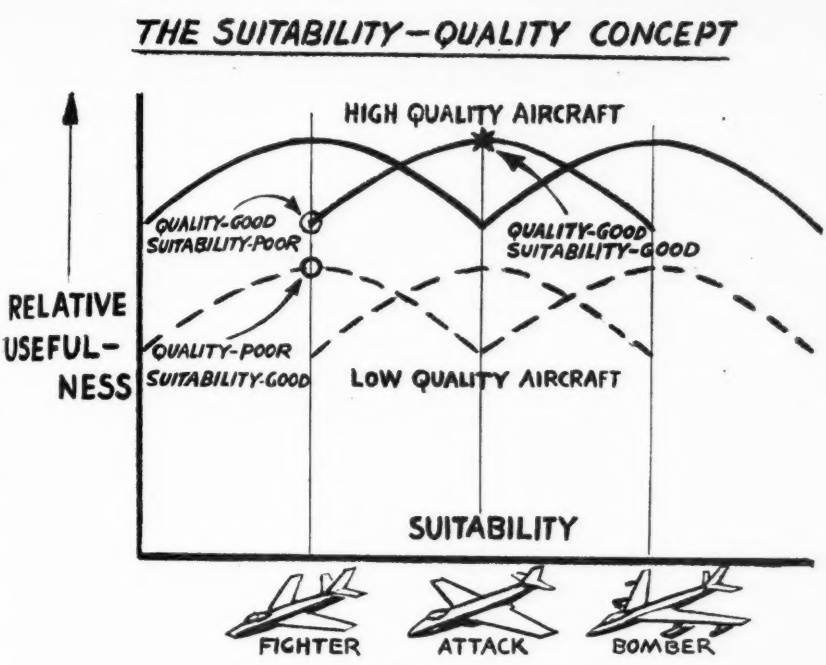


Fig. 8.

produced an aircraft which seemed to have little initial backing but which ultimately had a long and illustrious history.

The aircraft designer, civil or military, works to a set of rules established by the certificating or procuring agency which might be called "general design specifications." As the years go by, these detailed requirements of a general nature become more voluminous and can be the cause of inferior design. They can impede progress and increase cost greatly. If the designer fails to work hand-in-hand with the proper authorities towards the improvement of these general requirements, he is failing to give attention to one of the extremely important elements of good design.

Superimposed upon the general specifications are the *type specifications*, which cover items special to a particular kind of aircraft, and *model specifications*, which define a particular aircraft of that type. The tendency nowadays in some quarters, and it is a good one if not carried to excess, is towards type requirements that state the problem rather than specify exactly how it is to be solved—that is towards objective specifications. This has come about partly as a reaction against the rigidity of design which has crept into specifications, and partly as a result of increasing attention to the aircraft as part of an operating system designed to do a certain job.

On the subject of initial choice, many a project has been doomed from the start because it was ill-conceived. And, parenthetically, some well-chosen ones have failed because they were improperly executed. Thus there is the twin criteria of a well-tempered aircraft—suitability and quality. One without the other is insufficient, but entirely possible; both are necessary for success. Suitability comes first and is fundamental. No matter how high the quality, if the design is not suitable for its purpose it will fail. For example, an M.G. Midget is no doubt a *high quality* automobile, but its *suitability* as a hearse is poor.

The question of quality is considered next.

5. EXCELLENCE OF DETAIL DESIGN

Two aircraft designed to the same specification may differ widely in size, cost, and

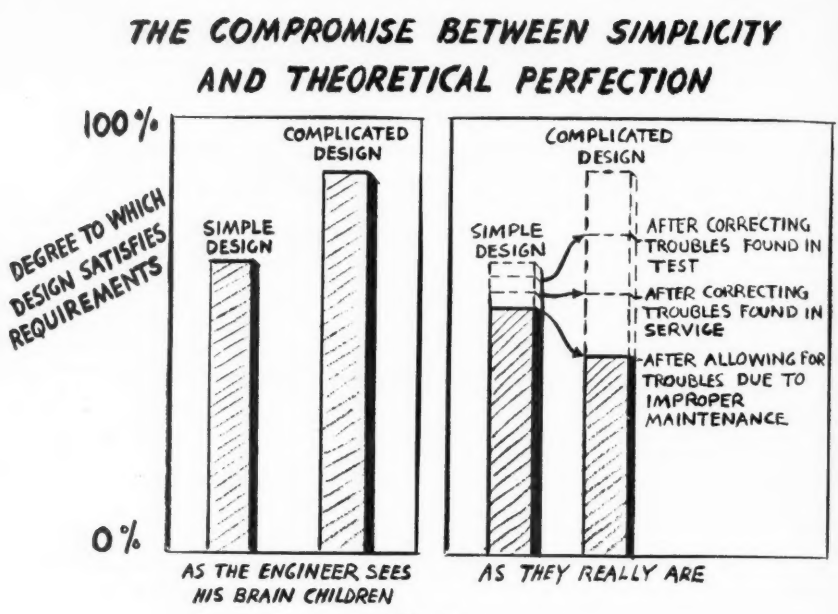

THE COMPROMISE BETWEEN SIMPLICITY AND THEORETICAL PERFECTION
100%
0%
DEGREE TO WHICH DESIGN SATISFIES REQUIREMENTS
SIMPLE DESIGN
COMPLICATED DESIGN
AS THE ENGINEER SEES HIS BRAIN CHILDREN
SIMPLE DESIGN
COMPLICATED DESIGN
AFTER CORRECTING TROUBLES FOUND IN TEST
AFTER CORRECTING TROUBLES FOUND IN SERVICE
AFTER ALLOWING FOR TROUBLES DUE TO IMPROPER MAINTENANCE
AS THEY REALLY ARE

Fig. 9.

weight simply because of relative quality of detail design (Fig. 8). In fact, much of the progress being made in the art consists in learning how to design a small, efficient aircraft to do the job previously done by a large complicated one. Not only does this hold true of the aircraft as a whole: it is also true of its components, down to the smallest parts. It is not always appreciated that a pound saving in weight empty may be compounded into ten or more pounds saving in gross weight on modern designs.

Quality, weight saving, and simplicity are all closely related. The simplest design that fulfils all desired characteristics is likely to be the lightest, with best performance, and the most dependable and reliable in its operation. In comparing a complicated design with a simple one, engineers often tend to compare them with both designs fully developed and working perfectly, just as the designer intended. In such a comparison the more complicated design often looks better. Unfortunately, all the intangibles act against the complicated design and in favour of the simple one (Fig. 9). Some of the intangibles are:—

Design time. Aircraft designs are not made in ivory towers; the design of each component must be scheduled, often far in advance of the time that the degree of complexity is known. Thus the complex design rarely gets as much time, in proportion to its needs, as the simple one. Very often the complex design can only be carried to the point where it barely works, and then must be frozen, under pressure from the schedule, while the simple design, with time to spare, can be refined. Thus those components which are simple tend to be more highly developed and free of service difficulties than those which are complex, because the amount of time required to get the complicated components to work at all leaves little or no time for improvement. This is the same thing on a small scale as the difficulty previously mentioned in connection with pioneering (Fig. 10).

Development time. The testing and development time required increase rapidly with design complication. Both budget and schedule pressures act to keep the more complex design from being as fully developed as a simpler one.

Maintenance. When a design is so simple that its method of operation can be grasped by a mechanic, it stands a good

chance of being properly maintained; while a design beyond the mechanic's understanding, in spite of maintenance manuals, placards, training courses, will rarely be as well maintained.

Carry-over of learning from previous designs is a major aid in reducing troubles in service. A design developed from a previous design, if the basic principles are still correct in the new application, is usually better than a completely new one. It takes engineers a few hard knocks to make them realise this; some never do. An engineer likes to take pride in a new and original design; he gets more satisfaction from this than from improving an existing one. It is a problem in psychology to get designers to take pride in the reliability and trouble-free operation of their product, rather than in the originality of their concept. On the other hand, using an old design in new conditions, to which it is basically unsuited, can be equally as bad.

5.1. Refinement of Design

When refinement of design is carried on with the idea of making it more nearly perfect, making it meet requirements more exactly, it often results in more complication and higher cost. This is the disease referred to as "perfectionism." Where refinement takes the form of conscious simplification, more often than not the result is a real improvement; unless carried too far, when it may delay the entire project. Even simplification, carried on too long, results in the basic concept falling behind the state of the art.

Complication is sometimes the path of least resistance for the designer. It is either the result of lack of knowledge or lack of adequate thought. The simple way of doing something is not usually the one that springs first to mind. To achieve simplicity it is often necessary to make a succession of designs of detail parts and throw each one away in favour of a better solution. Designing to a fixed budget rather than for a certain level of excellence may result in a spotty combination of good and bad elements. Designing to a fixed budget may be good if the budget is properly set. If it is too low the result is illusory; the cost of the original design is kept down but the costs of the subsequent development necessary to reach an acceptable level of perfection are higher (Fig. 11).

There is such a thing as inherent simplicity. Certain aircraft configurations lead toward straightforward and simple solutions of detail problems. Other arrangements make one fight every step of the way. It is often found also, as the design progresses, that small deviations from the initial requirements may make major simplification possible. Hence the importance of keeping the door

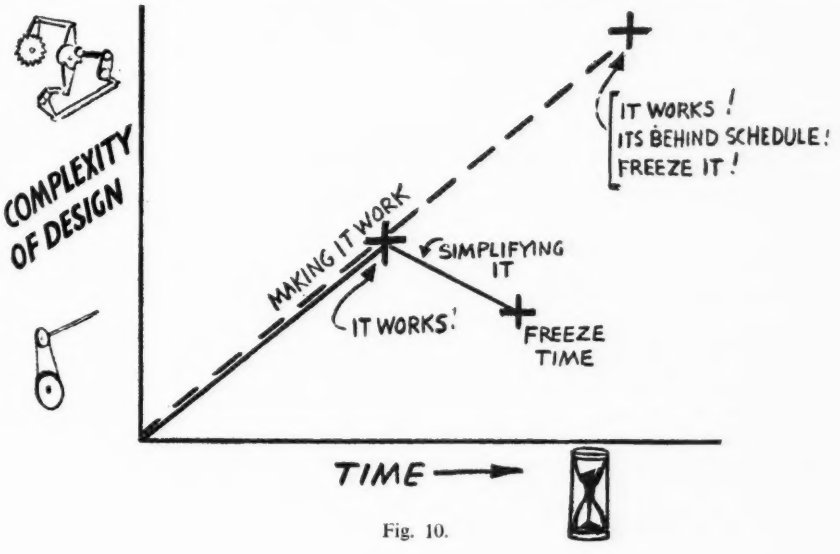


Fig. 10.

open to permit detail modification of the requirements for the general benefit of the whole.

5.2. Adaptability

Another quality which carries through, all the way from the general arrangement of an aircraft to the detail design of its components, is its ability to absorb future technological improvement.

An aircraft designed for one particular type and model of engine, in such a way that the replacement of that engine by another of somewhat different size and characteristics can only be accomplished by major structural alterations, is in a highly vulnerable position if that engine fails to come through as anticipated. Nor can it take advantage of successive future improvements in power plant as they come along through the years.

If the design is to remain well-balanced through successive increases in power some thought must be given initially to adaptability to carry more payload or even different types of payload. For passenger transport aircraft, the nature of these future changes can be fairly well anticipated in advance; with military aircraft, life and usefulness may be greatly increased by the installation of items of military equipment which were not even dreamed of at the time of initial design.

Wing area, plan form, aerofoil shape, and thickness ratio can be chosen for highest initial efficiency, or some leeway can be left for later growth. The same holds true for propeller diameter, on aircraft that use propellers. A long view is required to sacrifice immediate advantage for the benefit of longevity. A good aircraft may be in service for ten years or more and it is wise to keep its growth possibilities well in mind from the beginning.

5.3. Safety

Many things are placed on an aircraft in the hope and expectation that they will increase safety: sometimes such devices end up by doing just the opposite. If the failure of a safety device in service occurs more often than does the failure it is intended to protect against, and the consequences of its failure are more serious, it is certainly not a true safety device. Similarly, systems backed up by other systems which will presumably be used if the first system fails, in turn backed up by other systems, and so on, simply tend to multiply the insecurity. The constant shoring up of a poorly-conceived design with crutches here and props there,

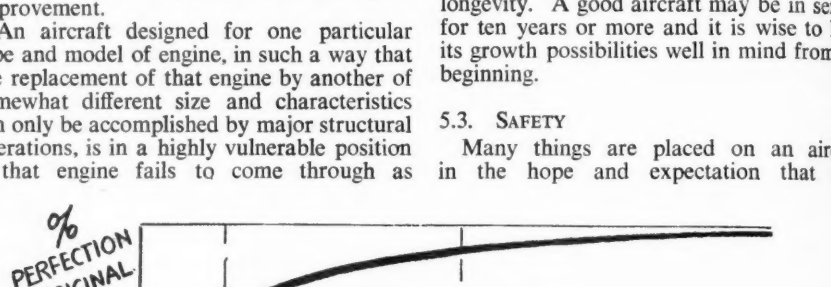


Fig. 11.

rather than taking a deep breath, plunging in, throwing the whole thing out, and replacing it with a properly designed component, is a penny-wise and pound-foolish policy.

5.4. Style

The aeronautical profession is beset by stylists and faddists. For a few years an attempt is made to operate everything electrically; then hydraulics becomes the rage; then there is a reversion to mechanical controls. At the present time there seems to be too much subservience to the god of electronics. Experience with all these things has shown that they all have their troubles and they all have their place; the one that will do the best job should be chosen, not the one which is familiar or personally preferable.

Proper functioning is more important than style or appearance and the designer who attempts to force his brain-child into a form which satisfies his aesthetic sense at the expense of its performance or flight characteristics has not done a good job. There is no need, as with cars, to maintain a distinctive appearance to identify the product. There is comfort in the fact that a device which is truly functional usually looks right and very seldom will offend the sensibilities.

Premature enthusiasms and *a priori* conceptions must be rigidly put to one side if a well-tempered aircraft is to be achieved. All through the design phase, choices have to be made between various ways of doing things. In the early stages these choices tend to affect the general arrangement and large items; later on they affect smaller parts. These choices must be based on the best information and analysis, with a minimum of snap decision or decisions influenced by emotion. The design must be progressively frozen as it goes along, neither too early nor too late. Too early is irresponsibility, too late is perfectionism.

5.5. Producibility

Aircraft production at best is not high-volume production and the type of tooling required, except for a few items such as standard bolts and nuts which are used many times in a single article or are used universally, is not high-production tooling. Such tooling is far too inflexible to accommodate itself to the constant stream of changes which is an inevitable concomitant of aircraft development. This lesson was learned the hard way by the motor industry during the Second World War, when it was pressed into the manufacture of aircraft. There has been considerable progress since aircraft were made by hand with little or no tooling. The correct middle course is to provide comparatively simple tools which can be augmented or duplicated if production is stepped up and which can be thrown away if the design is changed. This type of tooling often dictates the design. The true producibility of a design, as that term should be used, is the degree of its adaptability to the use of this type of simple tooling (Fig. 12).

5.6. Standardisation

Even the most conventional aeroplane is far from being an assembly of standard parts, but standardisation plays its part in good design. Good standards are those which result almost from necessity. They are developed because it is apparent to everyone that it would be highly inefficient not to develop them. Standards which are imposed by edict or which have to be crammed down people's throats are almost always bad standards with a stifling effect on progressive design. Standard practice, a broader type of standardisation than standard parts, can be a most useful adjunct to design by ensuring the uniform utilisation of best previous experience (Fig. 13).

6. DEVELOPMENT

Engineering, tooling, and shop should keep close to each other, mentally and physically, during construction of the prototype. It is a team effort and must be carried through in that spirit.

There should really be more than one prototype, not only because of the vulnerability of putting all the eggs in one basket, but also in order to shorten development time by running tests in parallel. In some instances, overall expense and time can be saved by having as many as ten or a dozen articles in flight test status concurrently. There are, in any event, good reasons for having at least two.

Experience shows that normally it takes at least as long to perfect a design after first flight as the time that has gone into it before first flight. For example, if it takes fifteen months to design and build the first prototype, it will be at least two and a half years from the start of design until the aircraft is shaken down and ready, in the design sense, for production deliveries. A

fairly conventional design or one with a high degree of carry-over from previous experience, may, upon occasion, be put into production before the first article has been tested, with reasonable assurance that the changes required will not be so drastic as to necessitate rebuilding. But usually there has to be a gap between the completion of the prototype and the start of production deliveries, and in some cases this may have to be as long as the time it took to build the first article. This would mean, in the example chosen of a fifteen-month aircraft, that production deliveries might actually start somewhere between two and a half to nearly four years from the beginning of design.

Very seldom is full allowance made for this in laying out schedules. As a result, aircraft which are truly not seasoned are delivered to service squadrons and spend much time on the ground, or deliveries of fully-developed aircraft come much later than optimistically predicted.

Flight test time is expensive, particularly on modern aircraft, and can be shortened by suitable preliminary research and ground or laboratory testing, including wind-tunnel testing. One of the difficulties of model testing in recent years has been the time required to build models and test them. The high speed at which these models must be run in the tunnel, the resulting high forces upon them, and the nature of the information which must be obtained from them, have produced model construction so intricate and test programmes so long that it has been difficult to get tunnel results early enough in the design of the aircraft to allow design modifications to be made while the drawings are fluid. In these circumstances, the wind tunnel tends to become a checking device rather than one for the collection of design information. The tunnel tests may look questionable but unless the curves are very definitely out of line, the temptation is to wait and see whether the aircraft exhibits these characteristics in flight, rather than to interrupt the design schedule and delay the project to make changes which may not prove to be necessary. If there were complete confidence in the validity of wind-tunnel tests this would not be so, but too often there is doubt as to the correlation between these tests and flight. The result is that the flight tests merely confirm the fact that the wind-tunnel tests are right; the engineers congratulate each other that they knew it all the time, and the aircraft comes back into the shop for a major change.

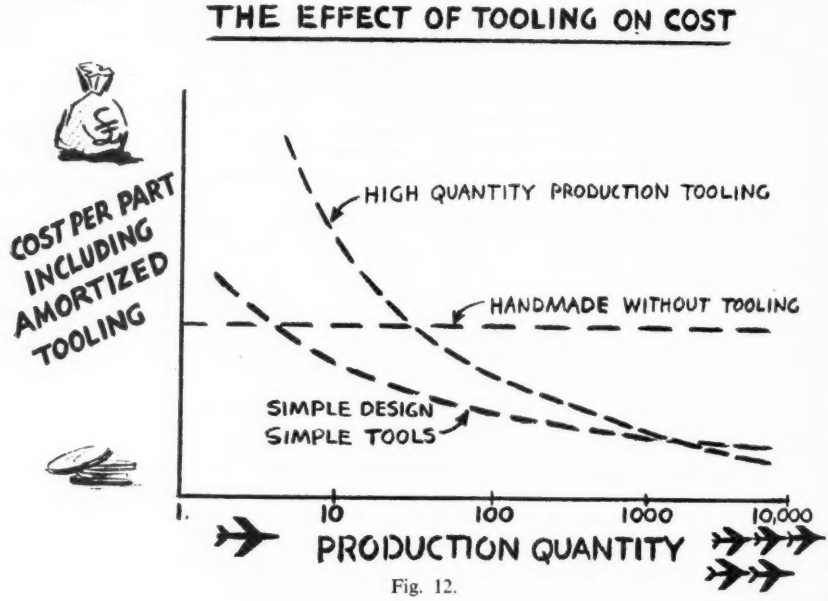


Fig. 12.

Research and testing carried out for the purpose of determining design information or of anticipating trouble and eliminating it before it occurs, have this in common; they require a certain degree of pessimism. The optimist either thinks he already knows all the facts or does not expect to run into trouble. Both imagination and judgment of a high order (and a certain amount of pessimism) are required to gauge the amount of research and testing necessary.

Aircraft design is not a complete science and never will be, so flight tests and service experience are necessary in order to check what has been done on the drawing board and in the laboratory. Flight tests provide the first real confirmation of the way in which the aircraft operates as a whole in its medium. Here also enters, too often for the first time, the human equation in the form of the pilot and crew. There is an increasing awareness of the fact that the experience and point of view of operating personnel should be intimately joined with that of the designer from the beginning, but even if this has been done, it still remains true that the crew, and particularly the piloting personnel, can only evaluate the aircraft, in the final analysis, by actually flying it.

The aeroplane is first of all a flying machine; there is no substitute for good flying qualities. Not only do they determine the ease with which it may be flown, its manœuvrability, and its day-in day-out performance; they are directly related to safety. If the pilot is at ease when he is flying the aircraft, if he knows he will have control over it under all conceivable circumstances, he does not tire and he does the right thing under stress. If he is nervous and apprehensive, or has to fight the controls in bad weather, his state of mind adds to the inherent difficulties. A good flying aeroplane must be obtained first of all; the rest can be added later.

Functional characteristics come next; do the installations on board the aircraft operate properly under all service conditions? It is not easy to check this point, because cold and hot weather, ice and snow, humidity and so on do not always turn up just when desired for test purposes.

With the great endurance and long range of many modern aircraft, and their standards of slow obsolescence, these functional characteristics have to be evaluated over long periods. As flying time accumulates the type of test information being obtained gradually shifts from that which establishes how fast it will go, how high it will fly, its take-off and landing distances, and whether electrical, hydraulic, and air conditioning

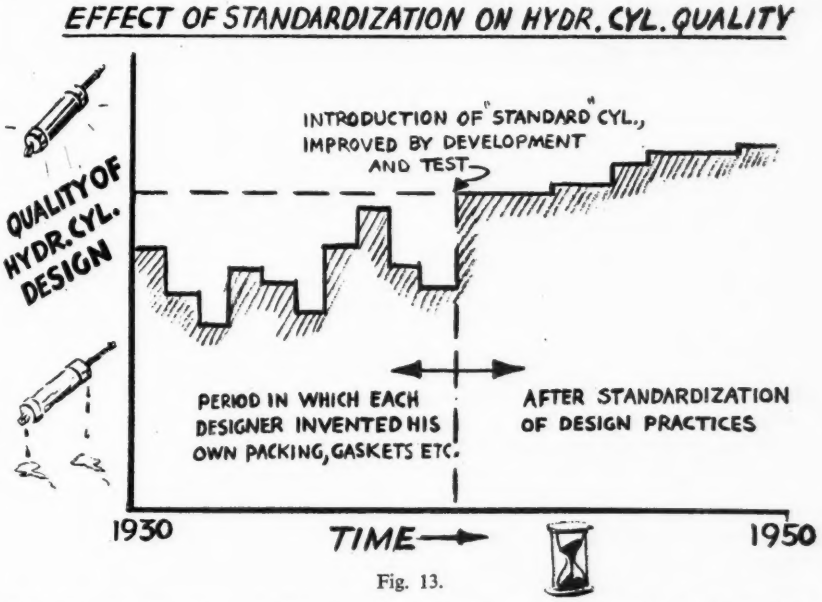

EFFECT OF STANDARDIZATION ON HYDR. CYL. QUALITY
QUALITY OF HYDR. CYL. DESIGN
INTRODUCTION OF "STANDARD" CYL., IMPROVED BY DEVELOPMENT AND TEST
PERIOD IN WHICH EACH DESIGNER INVENTED HIS OWN PACKING, GASKETS ETC.
AFTER STANDARDIZATION OF DESIGN PRACTICES
1930
TIME
1950

Fig. 13.

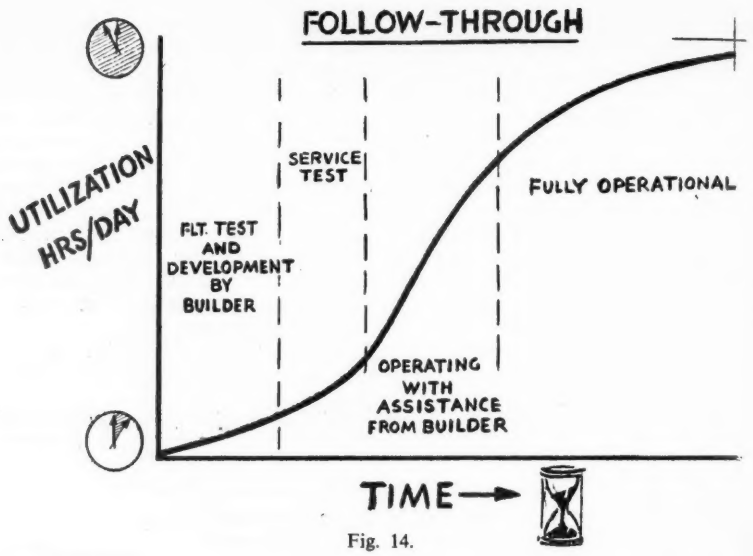


Fig. 14.

systems operate properly, to information as to which items have to be re-designed in order to lengthen life between overhauls or reduce the incidence of failure. The only way to get this information is to put in the hours and this is where flight testing merges into service testing.

In a sense development never ends, for so long as the aircraft lasts, improvements will be made in it. What is aimed at in the development period as defined here is to get the aircraft into such shape that it can go into service and do its job, month-in and month-out, and average not less than, say five, and perhaps as many as ten or more, hours of flying time per day. If it can do that, it is a well-tempered aircraft and justifies its existance. Every single item which goes to make up the machine as a whole has to come up to a certain standard of perfection in order to achieve this aim. This can only be done by systematic development over a reasonably long period of time; it cannot be cut short and if not done early it will be done more painfully later.

7. FOLLOW-THROUGH

7.1. Liaison with the operator

With the completion of the development phase the aircraft passes from the more-or-less direct control of its builder into the hands of the operator. This transition can be made easier if key men from the operating side are brought into the factory some time before delivery in order to become familiar with the aircraft and to share in its test programme. It also helps if representatives of the manufacturer go with the aircraft when it is delivered and stay with the operator for a while in order to help him to learn how to use it. This mutual assistance may start early and may continue for many years.

If specific training courses for key people from the prospective operator are thus set up in the manufacturer's plant some time before delivery of the first aircraft, these men can take the lead after delivery in carrying the familiarisation programme down through the ranks of those who are going to fly, service, and maintain the aircraft. In this educational process, actual working assemblies of various installations such as hydraulic and electrical systems can be a great help, set up in "bread board" style.

As service changes are made in delivered aircraft or as new aircraft of the same model with modifications go into service, the manufacturer must be prepared to give supplementary training to the operator. He must also assist in setting up refresher courses whenever it becomes apparent that troubles are being experienced because of insufficient or forgotten information.

There is always a tendency to criticise a new aircraft that is not fully understood. It

may be much better than previous ones but, just because it is different, it will seem strange and uncomfortable at first. An easy affection only comes after long familiarity and the period of becoming acquainted with something new can be very awkward if a well-thought-out and organised programme is not put into effect to bridge it over.

7.2. Facilities

In addition to knowing how to maintain and service the aircraft, the operator must have adequate and proper facilities. Here also, he can be assisted by joint planning well before delivery, so that the facilities are ready when they are needed.

Some of these facilities will be common to all or several types of aircraft which the operator uses. Others will be special to a particular one. For example, servicing stands, handling equipment and loading equipment often have to be specially designed and built. Sometimes the operator may do this, but more often these auxiliary pieces of equipment can best be developed by the aircraft builder with the advice and assistance of the operator, and can be delivered with the aircraft itself.

7.3. Spares

Nobody knows ahead of time exactly what items, and how many of them, will be needed as spares. Nevertheless, working from statistics accumulated on other aircraft, a reasonable list can be made during the initial design phase and these items can be manufactured with the early production aircraft. Later the spares list can be made more accurate. What items should be kept in stock at the operator's base, what items should be stocked at the manufacturer's plant, and what items should be made up as needed, are questions which only experience will answer.

Spares for military aircraft are often badly handled. Large surpluses and acute shortages go hand-in-hand and things are seldom where they are needed, when they are needed. The nature of military operations makes the problem of spares particularly difficult, but different services and different countries vary in the efficiency with which they cope with it. It should not be necessary to rob one aircraft to supply deficiencies in others, but such cannibal practice was often the only way to keep aircraft flying during the Second World War.

Military spares supply can be simplified by the use of air transport (Fig. 15). Depots can be farther from the front and fewer in number and there can be more flexibility in the whole operation if time in transit is counted in hours instead of in days, weeks, and even months.

7.4. Service

It is not enough to see that replacement parts are on hand when needed; changes must often be made in the design of parts to stop repeated troubles or lengthen service life. This requires continuous liaison with the operator. There must be a methodical reporting system, by which the manufacturer is made aware of the troubles as they occur, in sufficient detail to enable him to diagnose the cause and work out a cure. There must be almost continuous personal contact by men in the field. Extreme rapidity of handling the correction of troubles of a serious nature must be coupled with an overall system that overlooks nothing.

This service information has to travel both ways. The operator does not always need replacement parts, he needs instructions as to how to make his own correction on the spot, or he needs assurance that the correction he proposes to make is satisfactory. Also, the whole service record of a given aircraft has to be analysed by the manufacturer's service organisation and given to his designers so that they will have the benefit of knowing how their previous designs worked in practice when they design a new aircraft. Only in this way do they gain experience—and by going out into the field as often as they can to see for themselves.

7.5. Technical aircraft

Courses of instruction, personal contact and service bulletins supplement familiarity with the physical aeroplane itself, and the technical data that has to be supplied with it. Operating manuals, maintenance and service manuals, selected drawings, structural and aerodynamic data all represent a tremendous effort on the part of the builder of the aircraft to ensure that its operator gets maximum utilisation. If there ever was a day when the manufacturer could build his product and forget about it, it is gone forever.

Hours per day must be kept constantly in mind. An aircraft is designed to fly: while

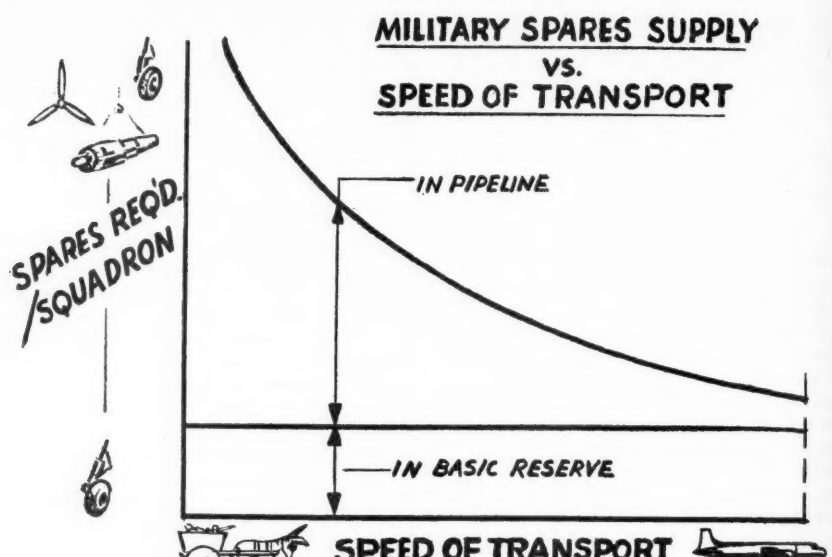


Fig. 15.

it is on the ground it is no good to anybody. This is always the case with the civil operators; with the military services it is true in time of war and potentially true at all times. In times of peace the military services have to assure themselves by actual test that their personnel are trained for continuous operation and that their aircraft are capable of it. In the development of the techniques that make this sort of operation possible, the services can be greatly assisted by the civil operators. Each owes much to the other. The civil operators would not have many of the devices they use had not the military services first developed them; nor would many of these devices ever have reached their present state of perfection had not the civil operators put them through months and years of almost continuous service. And through all of this trial period the designer must remain alert to help, to learn, and to put the combined experience into practice.

8. THOROUGH EXPLOITATION

8.1. Modification

A well-conceived, well-executed, and well-developed aircraft can usually be adapted to a wide variety of uses over a period of years, thus extending its market and lengthening its life span. If it has been made inherently adaptable in the first place, taking into consideration during original design the modifications likely to occur later, not only will these modifications be made easier but it will not be so difficult to make worthwhile major changes which could not be anticipated. If the foundation has been well-laid, the superstructure can be very elaborate.

It has been estimated that successful military aircraft undergo on the average during their useful life, modifications totalling at least one-half of their original cost. These are major changes introduced into the production line from time to time, either to improve performance of the basic model, or to fit it for different uses. In some cases these sub-models are even more numerous than this. The record for successful civil aircraft is much the same, for these find their way to many different customers, each of which requires variations in interior arrangement or in equipment to meet his own special preferences or conditions of operation.

There is little use bewailing this tendency towards non-standardisation. Modifications undoubtedly add to the cost, but without them the number of aircraft produced would

be much less, which in itself would in all likelihood raise the unit cost even more. At any rate, they cannot be avoided and it is the author's belief that it is for the general good that they be encouraged—in fact, that the designer bend every effort to see that every modification that looks at all promising be explored to the utmost. Efforts in this direction are often far more rewarding than switching to a completely new design. Every new aircraft design represents a heavy investment and a long development time. Obviously the greatest number of operationally useful aircraft could be produced within a given budget and time if they were all of one design. The excuse for having more is that (*a*) many different tasks have to be performed, (*b*) competition improves design excellence, and (*c*) the state of the art constantly improves, at a rate that cannot forever be matched by modifications. It follows that there should be no more designs than are required to cover the fields that are distinctive, with only enough duplication to provide the necessary incentive, and that the replacement of designs with new ones should be postponed by making modifications as long as they pay off. It also follows that a given design, once it has been perfected, should be made known to everyone who has a need for it.

8.2. New markets

It is not always apparent to a prospective user that such-and-such an aircraft is just what he needs. Tactical analyses of military aircraft and route studies of civil aircraft help to bring out clearly what they can do under certain specific conditions. Performance tabulations and flight demonstrations are useful, but detail studies, carried out jointly by designer and operator, of the way in which a given aircraft fits into an operation are also needed. Essentially, the problem is to see that every potential user knows that the aircraft exists, what its characteristics are, and what it can do for him in true comparison with other available aircraft. This does not imply high-pressure salesmanship in the sense of forcing something upon someone that he would be better off without, but rather the process of seeing to it that each worthy aircraft makes its place in the world, the place to which it is entitled in relation to other worthy aircraft. This effort is just as essential and just as praiseworthy as the others which have been discussed.

9. CORRECT SUCCESSION

Regardless of how good the aircraft may be, there comes a time, and it may come imperceptibly, when it becomes uneconomical to continue production. Any further modifications will cost more than their benefit. In spite of the best efforts it is falling behind the curve of progress to such an extent that to continue with it will only lead to the drying up of sales or will be an invitation to competition to enter the market with something distinctly better. (Fig. 16.) This is the time when a new model should be through its development phase and ready for operation. The new model must, therefore, have been started several years before. It is not enough to acknowledge the point of obsolescence when it occurs; it must be foreseen considerably in advance. The rate at which obsolescence comes about varies between wide limits. It may be so rapid as to make the time when a new model should be started agree exactly with the time of greatest apparent success of the current model.

It is always anticipated that an aircraft project will be a success and plans are laid accordingly. The road to eventual justification may be rough and there may be many times when it takes courage and vision to stick it out and not to give up too soon. On the other hand, it may in fact prove to be a mistaken venture: perhaps the sights set by the specification were too high and the attempt to meet them has produced a design that is strained and not easy, one that can never be truly successful because it is so complicated; perhaps the need which seemed so apparent at the beginning has faded away under changed conditions. The difficulty here, in view of normal human stubbornness and pride, is to accept the mistake as a mistake, write it off, take a deep breath, and put down a fresh sheet of paper.

This problem of succession, when applied to military aircraft, has some special elements that are worth noting. The losses that a given air force will sustain in battle against the enemy, depend upon its quality. If aircraft are not replaced from time to time with newer models, their attrition rate will be higher in the event of war. Replacements in wartime will then have to be more numerous, leaving aside the difficulty of getting them in time, and their total cost will be higher. This added cost will tend to offset the added cost that would have been incurred if more

modern aircraft had been secured in the first place. The penalty of allowing an air force to slip behind the state of the art through failure to renew, is so great that a drastic policy of scrapping existing military aircraft and replacing with new ones as soon as they can be made available will pay in the long run. In other words, as soon as today's bomber or fighter has been placed in production, tomorrow's should be started on the drawing board. (Fig. 17.) In fact, since not all designs are successful, more than one should be started.

The manufacturer who rests on his oars too long is overwhelmed by competition; the country that rests on its oars too long is overwhelmed by the enemy. There has to be a very definitely established policy of cyclical progression to maintain a place in this world of constant change.

In times past it may have been enough to rely on having new aircraft at all times ready for production. The pace of modern warfare is putting an increasing bonus on air fleets-in-being; the new aircraft have to be introduced into production and the old ones retired according to a prescribed plan designed to maintain a high level of quality. They have to be ready in quantity at any moment and the industrial potential needed for the replacement of war losses also has to be ready to be put into action at a moment's notice.

10. ADAPTIVENESS

Up to this point everything that has been said has given the impression that the production of a successful aircraft is merely a question of following certain rules. Starting with certain ingredients and mixing them in a certain way an assured result is obtained. Looking back over the examples of success and failure in the author's intimate knowledge, it is all too apparent that this is far from being the whole story. Things happen which might have been foreseen but were not; things happen that could not possibly have been foreseen. The total of these unplanned-for happenings often turns out to be the deciding factor.

10.1. Deficiencies in planning

This is an age of planning. It has come about because the very complexity of modern society, government, and technology requires that a great deal of attention be given to planning if things are to be kept under any semblance of control at all. At the same time, some of these problems are so intricate

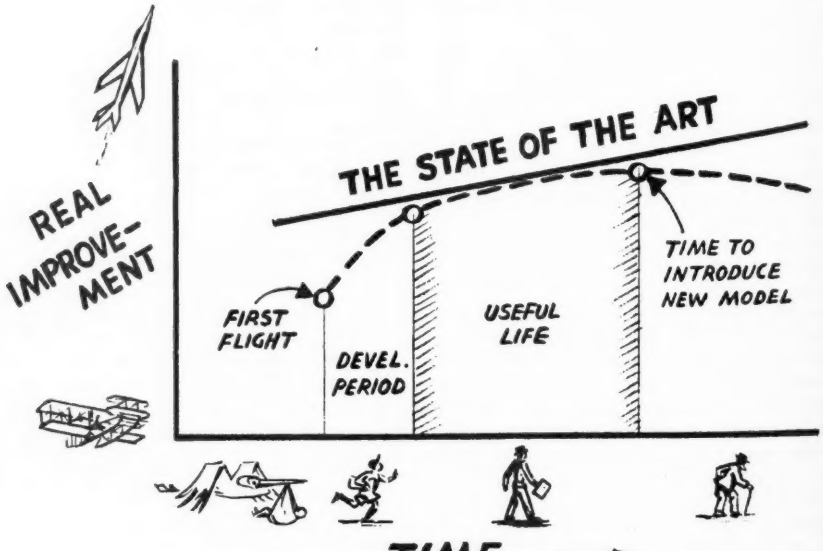


Fig. 16.

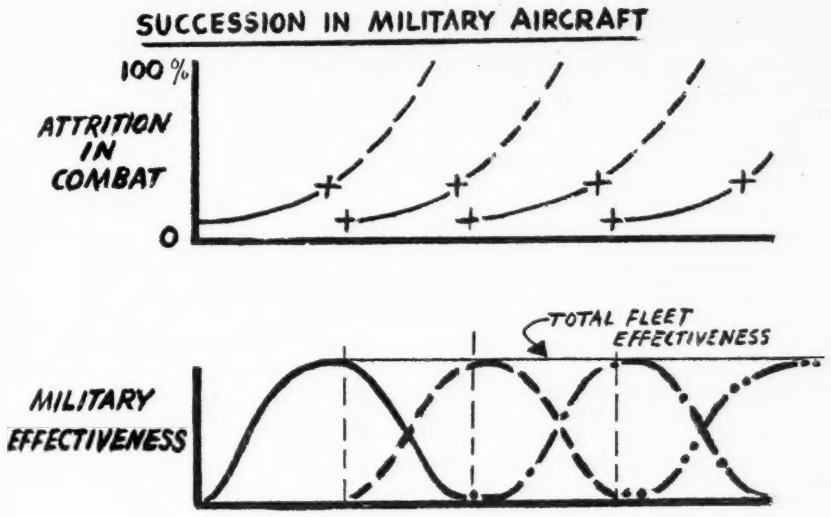


Fig. 17.

that it is absolutely impossible, at least within the time available, to establish all the variables with accuracy. The planning must therefore be imperfect and the danger is that it may cause those concerned to lose their resilience and their ability to be fast on their feet in dealing with the unexpected. The following is an apt quotation in this connection: "The absence of an undue amount of planning and co-ordination is an essential prerequisite of progress."*

10.2. Luck

Occurrences over which one has no control come in the general category of luck, good and bad. Sometimes plans can be made on an alternative basis when there is uncertainty as to what will happen, but often there is simply no way of anticipating the course of events. The thing to do in such cases is to be on the alert to seize upon, and use to advantage, the favourable happenings and to be prepared to take steps to minimise the effect of unfavourable ones.

There have always been a great many people in the aircraft business whose attitude is optimistic and who expect the best. Many projects never would have been started if this had not been so. A surprisingly large proportion of these have been successful, when a careful and thorough preliminary analysis would have shown their chances to have been much less than even. If no one drilled an oil well unless he were absolutely sure he would strike oil, petroleum production would be much less than it is. Certainly there are times when it is justifiable to take chances.

The qualities of mind referred to, flexibility, optimism, and lack of caution, are youthful qualities. Aviation will undoubtedly always be a field which attracts young men and one which is benefited by their presence. Those who have been in it for a good many years may be able to do their part by supplying the tempering judgment which only experience can bring, but they cannot allow themselves to think that they have all the answers. In fact, today no one knows all the answers. The problems are too numerous, the relevant facts are too many for any human memory—and automatic computing machines are still inferior to human beings in this regard.

As an illustration of the importance of the unplanned-for element, the case history of a familiar aircraft, the Dakota, is quoted. The specification for the forerunner of this aeroplane, the DC-1, was conceived in an atmosphere compounded of equal parts of

*Development of Aircraft Engines, by Schlaifer, a Harvard Business School Publication.

optimism and ignorance. It called for an aeroplane which weighed 14,000 lb. that would take off and fly on one of its two engines between points having an elevation of approximately 5,000 ft. with a terrain clearance between them of 7,000 ft. When finally completed, the DC-1 was 30 per cent. overweight and would never have been able to meet its specifications had it not been for two major and several minor developments which occurred during the course of construction and which were unforeseen at the time the contract was made. One of these major developments was the variable pitch propeller and the other was a marked increase in engine horsepower. The DC-1 was able to make the required demonstration flight on one engine (in this connection reference might be made to the Wilbur Wright lecture of 1935*) and met or exceeded its other performance requirements, but it was not good enough to be put into production without major modification. It was, in fact, the second attempt by an American manufacturer to build an aircraft of its class and type and it benefited by that fact, but it was still enough of a pioneering effort that, by the time it was done it was apparent that it could have been done better.

Not one, but two, major modifications were required before the Dakota or DC-3 came into existence. This, it is generally agreed, has been on the whole a successful aircraft. How successful it was going to become was certainly not foreseen. The tooling was designed for a quantity of fifty aeroplanes and it was thought at the time that this was rather daring. About seven hundred commercial aeroplanes were built from that tooling and duplicates thereof, but there probably would never have been more than one thousand DC-3's built had it not been for the war, another unforeseen element in the planning. At this point two completely new sets of tooling were built and nearly ten thousand military cargo versions were turned out. The aircraft originated in the early 'thirties and the last one was built some twelve years later, at which time changes were still being incorporated to increase the service life of parts and to take care of new items of equipment or new uses.

At this point it would have been normal, certainly, to have introduced a completely new model, but economic conditions were such that instead a major conversion, the Super DC-3, was introduced, which has carried production up to the present time and it is already evident that twenty years after this model was first designed, aircraft bearing the DC-3 designation will still be coming off the line. The DC-3 was lucky enough in its early years so completely to capture the market (and this was not the result of particularly good planning) that competition was thrown off balance. It therefore has had the benefit of a rather unusual position, but the fact remains that stern realism, undiluted by a certain light-hearted assumption of risk, might well have damped the project in its early stages.

11. CONCLUSION

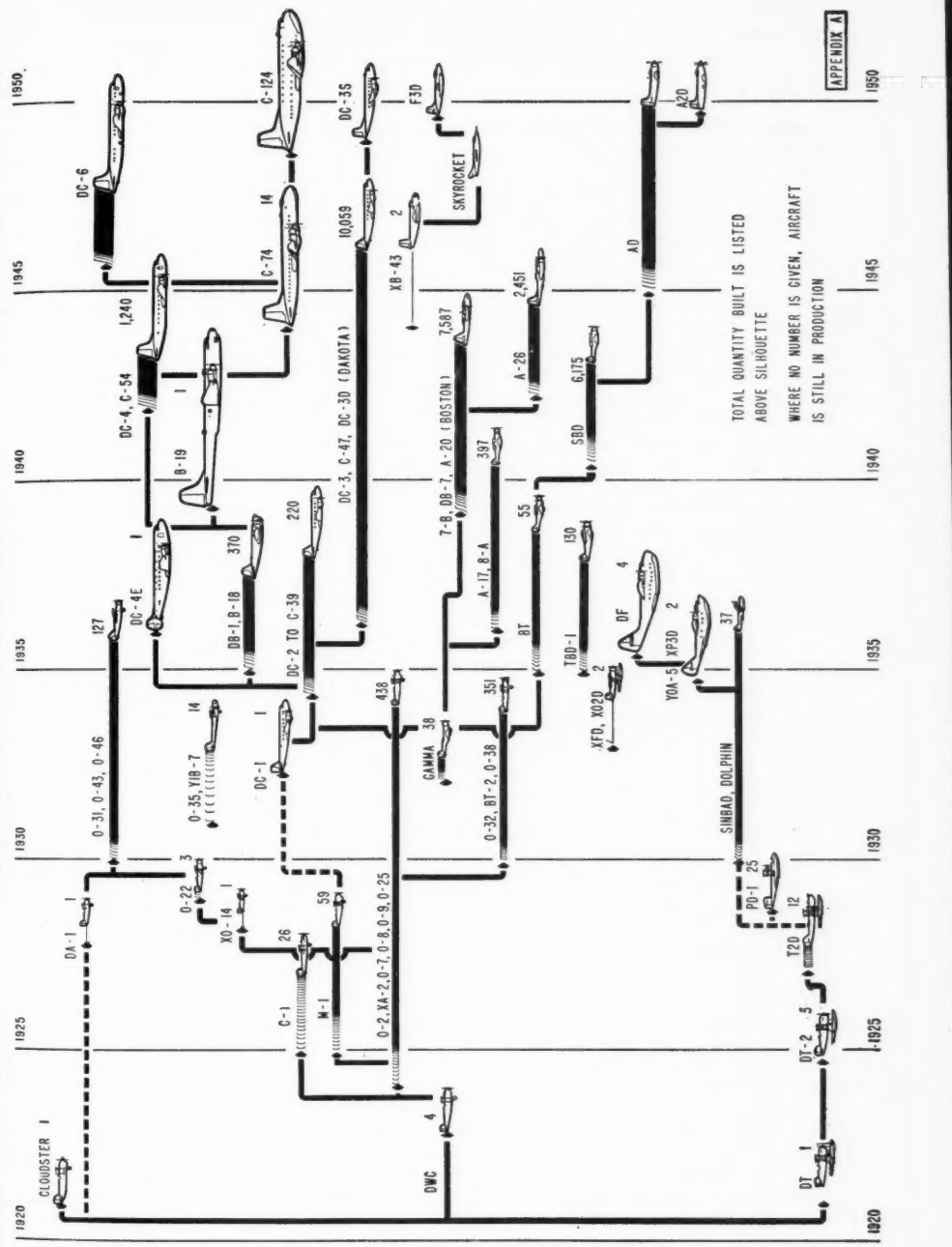
Implicit in this entire discussion of the well-tempered aircraft has been the idea of compromise between extremes. However easy to state as a principle, this is extremely difficult to adhere to in practice. It is not enough to bring to bear on these problems a high degree of technical knowledge; nor is it enough to adopt a pragmatic approach. In this connection there is an anecdote, credited to Dr. Karl Compton, which has come to mind again many times through the years.

It seems that a sister of Dr. Compton's, who lives in India, had occasion to have some wiring done by a native electrician. He came to her over and over again for instructions. Finally in exasperation she said, "You know what I want. Why don't you just use your common sense and go ahead?" Whereupon he made a grave, courtly bow and said, "Madam, common sense is a rare gift of God. I have only a technical education."

It may be agreed that common sense is rare, but not that it is entirely a gift of God. It is something which with great effort and tribulation can be developed. It grows out of experience and the proper blending of many skills and viewpoints. To the extent that those who work in the field of aeronautical science are able to so combine their talents, well-tempered aircraft in increasing numbers will be created and the great strength they can give to the free nations of the world will multiply.

*The Developments and Reliability of the Modern Multi-engine Air Liner. D. W. DOUGLAS. *Journal of the Royal Aeronautical Society*, November 1935.

APPENDIX A. A 30-YEAR HISTORY
1950
1945
1940
1935
1930
1925
1920
CLOUDSTER I


1920
1925
1930
1935
1940
1945
1950
CLOUDSTER 1
DA-1 1
DWC 4
0-31, 0-43, 0-46 127
0-22 3
XO-14 1
0-35, YIB-7 14
DC-4E 1
C-1 26
M-1 59
0-2, XA-2, 0-7, 0-8, 0-9, 0-25
DC-1 1
438
GAMMA 38
0-32, BT-2, 0-38 351
DT-1 1
DT-2 5
T2D 12
PD-1 25
SINBAD, DOLPHIN 37
DB-1, B-18 370
B-19 1
DC-4, C-54 1,240
DC-2 TO C-39 220
DC-3, C-47, DC-3D (DAKOTA) 10,059
7-B, DB-7, A-20 (BOSTON) 7,587
A-17, B-A 397
BT 55
T8D-1 130
XFD, XO2D 2
DF 4
YOA-5 XP3D 2
5BD 6,175
A-26 2,451
XB-43 2
SKYROCKET
F3D
DC-6
C-74 14
C-124
DC-3S
A20
AD
TOTAL QUANTITY BUILT IS LISTED ABOVE SILHOUETTE
WHERE NO NUMBER IS GIVEN, AIRCRAFT IS STILL IN PRODUCTION
APPENDIX A

APPENDIX B

IMPROVED TOOLS FOR HANDLING CLERICAL AND COMPUTING OPERATIONS

A number of clerical operations which are essentially of a book-keeping nature are being handled to an increasing extent today by calculating machines. Among them are payroll records, accounting and budget operations, parts listing, material releases, purchase-order writing, and the control of weight and balance. Not only are desk calculators used to perform the arithmetrical operations: machines of the book-keeping type with punch cards are also being used, resulting in less man hours and shorter elapsed time.

There are also a large number of more-or-less intricate calculations connected with aircraft design that are being benefited by the use of automatic computing machines: to mention a few, flutter calculations, dynamic analyses, system stability and response studies, strength analyses, trajectory calculations, and aeroelastic investigations.

The development of automatic computing machines for these purposes is proceeding along two lines, analog machines and digital machines. Analog machines are of two types, those which perform arithmetrical operation in a quantative manner, both input and output being scale readings, and those which set up electrical, mechanical, or other types of systems which behave in the same way as the system being analysed. Digital computers are also of two types, both using punch cards with input and output appearing as discrete numbers, the first designed to perform single operations on large quantities of data, the second to perform long sequences of operations, automatically coded, on relatively small quantities of data.

Modern flight testing often requires the collection of large amounts of simultaneous data, sometimes from unmanned vehicles such as guided missiles. Thus, radio transmission to the ground, called telemetering, is often necessary.

With all of these devices it is often necessary to handle large quantities of figures or output signals and translate them into curves or tables which may be read off directly in terms of standard units of measurement. So machines have been developed for drawing curves from such data and for translating figures and quantities into curves or *vice versa.*

All of these machines represent developments in that part of what has been called the cybernetic revolution which is gradually taking over those operations in the field of numbers, quantities, and data that are strictly clerical or mechanical, thus freeing more man hours for activities requiring judgment.

Major G. P. Bulman (Past President of the Royal Aeronautical Society) proposed the vote of thanks to Mr. Raymond: When the Council of the Society came to choose the lecturer from the American side to deliver the Wilbur Wright Memorial Lecture they sought the recommendation of the Institute of the Aeronautical Sciences to ensure that their representative was indeed worthy to maintain the high standard set by those who had lectured in the past. To have given such a lecture was an honour counted not among the least of the achievements of any man, however otherwise distinguished in his career.

From the applause of the meeting it was obvious how well Mr. Raymond had succeeded in maintaining that high standard, and their American friends, whose presence in such large numbers they welcomed, must indeed feel proud of their countryman. The lecture seemed to him to be a perfect postscript to the Third Anglo-American Conference which had been held at Brighton during the previous week. There they had listened to what might be likened to the hurly-burly of an important and complicated law suit, and heard many professional expert witnesses and counsel for the prosecution and defence arguing about many complicated details. In Mr. Raymond's lecture they had heard the summing up of a very competent judge, a distillation of wisdom and experience, tempered with tolerance and understanding of humanity, and withal a sense of humour. He had put the whole thing in its right perspective. All of them who were, or had been, intimately concerned with aviation, with its increasing and inevitable specialisation, and the need for many to get to know more and more about less and less, might feel perhaps that their own

individual achievements and personal joys and sorrows were important, whereas in fact it was only their impact on others that mattered. Mr. Raymond had provided a perspective, just as did their own great *maestro*, Sir Henry Royce, who used to say, "Well, boys, what does the job want? That is all that matters."

The title of the lecture was "The Well-Tempered Aircraft," but Mr. Raymond, unconsciously perhaps, had given them also a recipe for a well-tempered world, a point he did not hesitate to introduce in the light of that wonderful, indeed inspired, speech by Lord Brabazon at the Anglo-American Conference Dinner at Brighton. They in aviation, particularly in America and Britain, could do so much for the world, not only by their achievements in science and technique but also by the closer relationship between them, and through them, their countries. Aeronautical people in America and in Britain, in venerating together the great Wilbur Wright, must surely feel a great responsibility. They had in their hands the making of a spear, air power, on which the maintenance of peace might well depend. It was for them together not only to produce the spearhead of maximum penetration and technical quality, but also to combine individually to provide the shaft behind that spearhead which they hoped, by reason of their strength, they should never require to use.

It might be said that individually they could do little. The parachute which brought man safely to earth when his man-made contraption broke up in the air was made from the gossamer spinning of many insignificant silk worms.

In proposing this vote of thanks to Mr. Raymond, it was not merely the normal polite and conventional thing that he did; he invited them to thank Mr. Raymond most sincerely for having given them not just a competent and interesting paper to be read once, and put away on the shelf, but something which should be read and re-read in every office and department concerned in the progress of aviation, something which was a challenge to the future.

Reverting to his simile of the summing up of a trial he would ask, "Who will give the verdict?" He suggested that they themselves were under trial and that the verdict would come from future generations as to how they had used their abilities and power—generations now waiting in the ante room of posterity.

Captain J. Laurence Pritchard, seconding the vote of thanks: The task was somewhat difficult for him, for after some 30 years he now found himself on the other side of the iron curtain!

He would like to say what a great pleasure it had been to read—and hear—the lecture. It was one of the best lectures he had attended in the series of Wilbur Wright lectures and he predicted it would become a classic. It afforded him greater pleasure than he could express to second the vote of thanks.

Following the lecture a reception was held at 4 Hamilton Place, W.1, by the President, Major F. B. Halford, C.B.E., F.R.Ae.S., and Mrs. Halford, and the Council and their ladies. More than 500 members and guests were present and were received by the President and Mrs. Halford. During the evening music was played by the Sextet from the Central Band of the Royal Air Force (by kind permission of the Air Council) and films taken during the Conference at Brighton were shown.

HIGH-SPEED FLYING*

by

Squadron Leader JOHN D. DERRY

THE TITLE of this paper gives only the broadest indication of the line it is intended to take. Other papers with similar titles have been read by those connected with the design or aerodynamic side, but this paper is mainly concerned in conveying the pilot's own view of the problems of high-speed flying.

The paper is divided under the following main headings:—

1. The obstacles to negotiate at high and low altitude.
2. The approach to high-speed investigation and means of obtaining test results.
3. Present and future requirements of research aircraft.
4. Pilot safety measures.
5. Some requirements of a pilot engaged in high speed research and development flying.

For the most part it is intended only to cover research and development flying. This necessarily entails some reference to combat, which is in itself a separate field.

The problems confronting a pilot who sets out to explore the behaviour of contemporary aircraft at high speed are considered first.

High Mach numbers and high indicated air speeds are now irrevocably joined in a modern high-speed aircraft. But it is still possible to isolate the effects of pure compressibility from the problems associated with high air loads. It is important for the pilot, as well as the aerodynamicist, to achieve this isolation. To some extent their desire to initiate all research at high altitude springs from the same source. For a given true speed the indicated speed or dynamic pressure is halved at 40,000 ft. Also the speed of sound is 100 m.p.h. slower above 35,000 ft.

The effects of distortion and changing lift coefficients are technical problems which do affect the pilot in some degree. But there are other considerations more directly in the pilot's interest.

In the first place, up to now it has been, and will be for some considerable time hence, impossible to break a normally strong research or fighter type of aircraft above 35,000 ft. This is a fact, often not appreciated, which makes nonsense of most popular ideas about flying through the "barrier." Secondly, control forces are low so that any increase due to Mach number does not immediately give rise to difficulties and at the same time rapid corrections can be made. Power operation and other devices largely obviate such considerations, but at present only a few aircraft in Great Britain have such controls and the problems of manual operation must be considered. A third advantage of more than passing interest to the pilot is the ability to abandon aircraft without encountering the shattering effects of high air pressures. It follows from this that at the higher altitudes a small margin of time exists in which to sum up a situation in which the possibility of baling out arises. It is hoped to show that such a situation is unlikely to occur at high altitude.

Consider what are, in fact, the pilot's main worries during investigation at high altitudes; that is to say above about 30,000 ft. Problems not directly connected with speed, for example the effects of altitude on the pilot, can be disregarded for the present.

Experience has shown that compressibility effects produce the following general symptoms: variations of hinge moment, flow breakaway causing buffet, changes in stability, tab and control ineffectiveness, and large unpredictable trim changes. Of these, the last two are the most serious obstacles

*A Lecture given before the Graduates' and Students' Section of the Society on the 30th November 1950 at 4 Hamilton Place, W.1.

Squadron Leader Derry is experimental test pilot with the de Havilland Aircraft Co. Ltd. In 1948 he set up a new record for the 100-kilometre closed circuit and he was the first British pilot to reach the speed of sound.

and have given rise to the popular stories which have only served to confuse the issue. As already mentioned, the advent of power controls has brought new solutions to these problems but manual controls are dying hard and a great deal of the early high subsonic work has been completed without recourse to the unconventional. Most of the original reports concerned very high stick forces and tab ineffectiveness; in most cases one following on the other. It is difficult for a pilot to be aware of the stick position or elevator angle and consequently it was not easy to recognise when the high forces were due to high angles. Power controls have shown that all the available control movement may not be sufficient to cope with very strong trim changes. But they have permitted an increase in the limiting speed. The most troublesome trim change is nose-down, both for manual and power controls. In both cases the final result can be a very steep dive, either because of the inability of the trimmer to relieve sufficiently the stick force, or because of complete ineffectiveness. It is difficult to know when it is due to a large trim change and when it is a case of a small change, plus losing control power. It is obvious then, that a serious nose-down trim change can result in a genuine loss of control.

In practice, however, the onset of the trim change is rarely so sudden that some form of corrective action cannot be taken. Two examples of this form of vice might be of interest; one with manual controls, one with power boost.

The first concerns the Spitfire. It is often forgotten that jet aircraft have not got the monopoly of the high Mach number field. In fact only very few jets have exceeded the limiting Mach number of the Spitfire. Regular tests were made up to $M=0.86$ and on one occasion $M=0.92$ was reached by Martindale, then of the Royal Aircraft Establishment.

The present illustration, however, concerns the moderate Mach numbers. At $M=0.83$ or so, a strong nose-down trim change occurred building up rapidly at $M=0.85$ until full nose-up trim was insufficient. At $M=0.86$ the aircraft could not be pulled out of the dive with a 150 lb. stick force. In this case the uncontrolled dive lasted only for a short time owing to the very big drag increase on closing the throttle in fine pitch.

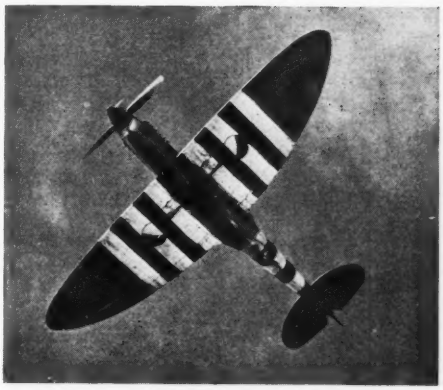


Fig. 1.
The Supermarine Spitfire XI.

The second example concerns the D.H. 108. In this case the uncontrolled dive resulted from a serious loss in elevon effectiveness which resulted in having to use the full amount of up movement to trim at $M=0.98$. Consequently a relatively small nose-down trim change at $M=0.99$ was sufficient to carry the aircraft into a dive. Additional trim was provided by trim flaps but these quickly became ineffective and only very prompt action could prevent a vertical

Fig. 2.
The D.H. 108.

Fig. 3.
The D.H. Hornet.

dive developing. Unlike the Spitfire there was no big drag increase; indeed no means of recovery existed until the terminal Mach number fell below that at which control was lost. This condition was realised at 30,000 ft. in the D.H. 108 where the terminal Mach number was 1.0 and a slow recovery became possible. It was completed by 25,000 ft. at $M=0.95$, or so.

These two examples illustrate the worst effects of Mach number and also indicate that even the extreme case is not disastrous. The author is unaware of any crash which can be directly attributed to loss of control at high altitude as a result of compressibility effects. On more advanced aircraft the results of an uncontrolled dive might be more serious, as the extra weight and lower drag might result in the dive continuing until structural limits were reached.

Nose-up trim changes are more irritating than dangerous at high altitude. A strong nose-up trim change with manual controls may prevent further acceleration since an involuntary recovery takes place. The Hornet was one example of this. At $M=0.75$ a 100 lb. push force caused no increase in dive angle. Several modern jets have suffered from large nose-up trim changes. The only dangerous case is at medium altitudes when a sudden or unstable nose-up pitch or rapid trim change may subject the aircraft to high accelerations. At the altitude being considered such a form of vice, at the worst, results in a high g stall.

It has already been remarked that it is impossible to break a high-speed aircraft above 35,000 ft. This is because the g loading at which the aircraft stalls is below that at which structural failure occurs. Given powerful enough trim changes with insufficient or heavy control, coupled with instability or lack of damping, an unintentional stall may develop. The possible consequence of such a state of affairs may be as follows.

It is necessary, in combat, to use the aircraft to its limits and g stalls are a common occurrence in fighter aircraft. For this reason the stall must be quite safe and in fact on present-day fighters it is innocuous, giving no more that a slight drop of the nose or one wing and accompanied by considerable buffeting. Reduction of g gives immediate recovery to positive control.

Aircraft with swept wings, however, exhibit the now well-known tip stall before reaching their maximum lift and this results in a rapid and unusually large trim reversal, so that the aircraft tightens suddenly in the turn or pull-out sometimes before the pilot can check it. Although this makes the stall more sudden, again there has been little trouble in stalling and unstalling satisfactorily. For tailless aircraft, or a conventional aircraft with spinning tendencies, it is possible that risk of spinning might exist. Fortunately in most aircraft the g stall is straighter than the normal stall.

A stall, then, is not likely to prove catastrophic, and in practice is rarely

experienced unintentionally at high Mach number.

Since stalling has been discussed, it would be as well to mention the characteristics of aircraft with relatively low critical Mach number in which the maximum lift falls off rapidly in this region. The result, as would be expected, has all the symptoms of a *g* stall with buffeting, wing dropping, lack of control effectiveness and sometimes, instability. Operational aircraft of this type in service for the past few years have been cleared up to this point. This, perhaps, illustrates the absence of alarming behaviour which is so often referred to.

The only trim change which has not been discussed is the lateral.

Straight-winged aircraft with relatively thick wings, *e.g.* Meteor and Vampire, experience lateral trim changes or even sharp wing drop in the advanced stages of compressibility misbehaviour. But the more gradual wing heaviness, as it is sometimes called, of the swept-wing types is more serious because it may be the only limiting feature. Because there is usually adequate warning these lateral trim changes are seldom dangerous, although in the latter stages full aileron is often ineffective in maintaining an even keel. If this stage is reached, slightly unusual attitudes can occur and a steepening of the dive is perhaps the most uncomfortable aspect of the vice.

Many swept-wing aircraft are susceptible, in varying degree, to what has become an innocuous but sometimes deciding factor in the ultimate limit. In some cases it has been found possible to raise the downgoing wing by applying rudder towards that wing; that is to say, the reverse of normal corrective action. The effect of yawing or unyawing swept wings at high Mach number can be understood but it remains a new reaction for the pilot to master. Lateral control is bound to be more satisfactory to the pilot and development to this end is in progress. Very large ailerons are an obvious solution.

Of the broad symptoms of compressibility outlined at the beginning of this section all are seen to be at their worst when connected with trim changes.

Individually they amount to little more than a distraction at high altitude, although they can be serious at low altitude.

Variation of hinge moment can result in over-balance of controls or, more commonly partial balance, producing what is known as hunting; an oscillation of the control, usually the elevator, which can be checked by the pilot and, if a serious obstable, can usually be put right by small adjustments to the control balance.

Buffet comes in the same class although it is often harder to reduce. With very few exceptions buffet comes from the tail, although possibly as a direct result of the wing wake. Buffet can be tolerated provided that it is not of a frequency likely to cause fatigue of the structure. This is difficult to establish and sometimes necessitates the fitting of a vibrograph.

Control and tab ineffectiveness have already been discussed in conjunction with trim changes. The difficulty of separating these two causes of vice has been pointed out. In the absence of trim changes the result is obviously much less troublesome but with further acceleration in mind it has to be remembered that quite small variations in configuration can induce changes in effectiveness out of all proportion.

Static stability is the essence of trim changes but manoeuvre or dynamic stability has a direct bearing on the extent to which a longitudinal trim change may be investigated or negotiated. An example of this is to be found in a nose-up trim change coupled with instability in manoeuvre, referred to earlier; a stall at high altitude, but structural failure at lower levels, is a possible outcome of such circumstances.

Summarising the effects of high altitude and high speed it can be said that there is a small element of risk, but that the nose-down trim change which contributes more towards it has to be faced. In the transonic region it cannot be avoided ultimately.

Going on to the pilot's problems at low altitude, it should be explained that the extremes of both cases are being described. There is obviously a merging of the two and in the process of combining the separate effects lies the secret of approaching the low altitude problems with the minimum of risk. The gap between the two is purely arbitrary and as speeds are increased it tends to close.

What are the problems involved when high dynamic pressures are combined with the effects of compressibility? The indicated speeds considered high today are inevitably at moderately high Mach number but with improved design, particularly sweepback, aeroelastic effects can be explored without much interference from compressibility.

Fig. 4.
The D.H. Venom.

By far the most unacceptable of all forms of aircraft misbehaviour is flutter. Under this heading is included any undamped oscillation of control or aircraft with a frequency greater than a half-cycle per cycle. Below this frequency some control or deceleration is possible before high stresses are reached. Under any other conditions the only possible action is immediate deceleration and a climb; and with existing air brakes this is likely to be too slow! It is quite unsafe to investigate flutter or oscillations in flight unless a condition of indicated air speed and Mach number can be found when damping is neutral or just positive. In these circumstances a limited amount of investigation is possible but in general any attempt deliberately to induce an oscillation at high I.A.S. is very unsatisfactory.

With the present trend for flutter speeds to rise, serious flutter is not a cause for anxiety at high altitude, but the need for a careful build-up in the Mach number-I.A.S. combination cannot be too highly stressed.

Pitching oscillations due to lack of damping are even more unpleasant than control flutter. It has been possible to make useful investigations into this phenomena because the fall in damping which gives rise to the oscillations has been reasonably progressive. Once again extreme care and much repetition is necessary in building up speed when this type of oscillation is expected. Ideal conditions—absence of turbulent air, failure to operate all controls at increasing speed, and so on, may result in the loss of damping remaining undetected until the point is reached where damping is negative.

This latter type of flutter or oscillation has so far mainly been confined to tailless aircraft, but the possibility of serious loss in damping when big increases in Mach number are possible must not be forgotten. Lack of damping in roll and yaw in fact have been experienced at high Mach number in the United States and under certain conditions of high I.A.S. in the United Kingdom. A good illustration of a pitching oscillation was provided by the D.H. 108 in which damping was reduced with both Mach number and I.A.S. During investigation of high M/I.A.S. combinations when the presence of a loss in damping was apparent and consequently, increases were being made very gradually, a serious state of affairs occurred in spite of all possible care, in which an undamped oscillation built up to $+4$, -3 g at the rate of 3 cycles/sec. The final loss in damping from neutral to seriously negative occurred over a Mach number range of 0.005, a variation which can occur through gusts, apart from the difficulty of maintaining M to such extreme accuracy.

At the same Mach number, however, at lower I.A.S., it was possible to reach a state of zero damping with a lower frequency which allowed controlled investigation to be made.

Aerodynamic noise may produce an uncomfortable sensation of speed but may also indicate a flow breakaway. A recent example of this occurred on the night fighter Venom. The canopy had been bulged to provide increased headroom. On reaching $M=0.75$ at indicated speeds above 350 knots a roaring noise began. It became progressively worse with I.A.S. and an increase in M at 400 knots and over produced a curious whip crack effect. In moist air at low altitudes the area of high suction could be seen by the presence of a vapour cloud over it. At $M=0.78$ the actual shock position was indicated by an opaque area of mist extending several inches at right angles to the surface. A lower canopy improved this but the suction is still sufficient to produce mist under certain conditions at $M=0.82$ and above.

Most people have noticed the mist effect on aircraft wings during a high-speed fly past. During this phenomena the effect of a shock formation described above can often

be seen on the wing from the cockpit as a more opaque area of mist in the centre of the cloud. It is also sometimes possible to see the shadow caused by light refraction at the shock but this depends on the position of the sun and other variables. The author's experience is limited to one occasion in a Spiteful at $M=0.83$ but the Americans have proved that careful positioning of the aircraft relative to the sun can make the shadow visible from any cockpit position.

It is perhaps unnecessary to point out that in spite of avoiding serious forms of vice there is always a psychological effect from high indicated speeds, at low altitude, due to noise, turbulent air and at present the inability to abandon aircraft, which will always make this side of high speed flying the least pleasant and the most spectacular. As aircraft speeds rise so the sensations remain with, or near, the critical speeds so that in a well-designed supersonic aircraft, 800 m.p.h. I.A.S. will seem little worse than 600 m.p.h. I.A.S. on a present-day aircraft capable of 650 m.p.h. High speed flying, in its true sense, means flying at, or near, *limiting* speed. It is probable that the Wright Brothers found 30 m.p.h. extremely trying.

HIGH SPEED INVESTIGATION

Turning now to the methods used in high-speed investigation, discussion will be confined to the techniques developed over the past couple of years which, it is hoped, will bear little relation to those of the near future.

Straight winged aircraft with moderately thick wings (12-14 per cent.) were attaining $M=0.8$ or so in level flight and this was close to the vice Mach number or to the point at which the drag rise called for a steep dive.

A great deal of work was done on such aircraft up to $M=0.86$ to 0.88. On the Spitfire, and to a lesser extent on the early jets, very uncomfortable dives were necessary to obtain these Mach numbers. The arrival of the swept wing aircraft at once led to Mach numbers in the 0.86 to 0.90 bracket in level flight. This might seem to be the answer; but it is not. The swept aircraft exhibits normal behaviour up to its level Mach number and consequently its real value for research lies in its being able to attain the 0.95 to 1.0 bracket. And so it is necessary to dive again.

This may seem obvious, but it is mentioned because it does mean that the ultimate work must still be done in a dive. On this fact hangs the framework of all methods of investigation.

It has been shown earlier that it is imperative to build up speed and Mach number slowly. At high altitude this is difficult when controls are sloppy and stability possibly doubtful.

Furthermore the rapid change in the drag results in very large changes in dive angle if a steady acceleration is to be observed. To use the D.H. 108 again as an example. A 30° dive at 40,000 ft. was sufficient to reach $M=1.0$ at full power while at 30,000 ft. the terminal Mach number is 1.0. Admittedly the latter case is with power off but at this height in a vertical dive the power only represents 15 to 20 per cent. of the total thrust.

The region of the drag rise is well indicated to the pilot in a steady dive by a relatively sudden disappearance of acceleration. Below the drag rise the opposite effect results in a feeling that the aircraft is "running away." This is one of the main differences noticeable when first flying a jet and is equally noticeable between flying say, a straight winged aircraft of 12 per cent. wing thickness and a swept wing version of the same type with a 10 per cent. thick wing. In one case the propeller provides a big increase in drag while in the other the variation in compressibility drag rise is responsible. Air brakes have been fitted to alleviate this effect but their use during careful acceleration is undesirable owing to their coarse action.

From the foregoing it is obviously desirable, and possibly vital, to know the dive angle required to obtain a range of speeds at full throttle. Some means of measuring this is necessary; dive angles are always overestimated by pilots, particularly on aircraft in which the pilot is in the nose. With this knowledge it is possible to set a certain dive angle which can be held constant with no risk of exceeding limitations. This means that no change in control angle is necessary apart from trim changes and a steady condition of 1*g* can be maintained. This is most important in certain aircraft where change in lift coefficient or control angle affect compressibility behaviour.

This type of approach was experienced by the author when it was discovered that when the elevator angle was reduced in attempting to steepen the dive, a violent unstable pitching occurred. It was found possible to get

over this serious obstruction by keeping the control angle above a certain value. This could only be done by pre-setting a dive angle to reach a predetermined speed and this method was used on every subsequent run up to these Mach numbers.

Accurate dive angles may be required at low altitude on aircraft which have a limiting I.A.S. near limiting Mach number and which are unable to reach this speed in level flight. In these circumstances a steep dive may be necessary to obtain limiting speed but in doing this it becomes very easy to exceed the limiting Mach number at a lower I.A.S. To reach limiting I.A.S. without exceeding the Mach number limitation the maximum speed must be obtained as near to sea level as possible.

If it is possible to make a long dive from a medium altitude at limiting Mach number this problem is less serious, but on occasions it is necessary to accelerate rapidly through a much smaller height band and here a previous knowledge of dive angles at constant thrust is extremely helpful, if not vital.

The importance and critical nature of control angle variation at high Mach numbers, coupled with the possibility, due to large trim changes, of over-stressing the tail at a high M/I.A.S. combination, leads to an instrument, previously familiar only to the aerodynamicist, becoming an important source of information to the pilot, namely the Desyn.

The coming of power controls has still further increased the case for the Desyn since in aircraft where irreversible controls are fitted and feel is largely, or completely, artificial, stick forces are no longer useful in the assessment of stick-free stability and control angles assume as great a significance to the pilot as stick forces did on aircraft with manual controls.

Variation of control angles have been known to alter completely the compressibility vice and by control angles are meant any movable flap or control liable to be used at high speed or Mach number. Furthermore, as has already been seen, the effectiveness may vary greatly over a relatively small speed range. It is important therefore to operate all controls to the fullest possible extent with each small increment in Mach number. It is extremely disquieting to discover that the elevator has become over-balanced only when attempting to change the dive angle, or that a recovery flap has become ineffective

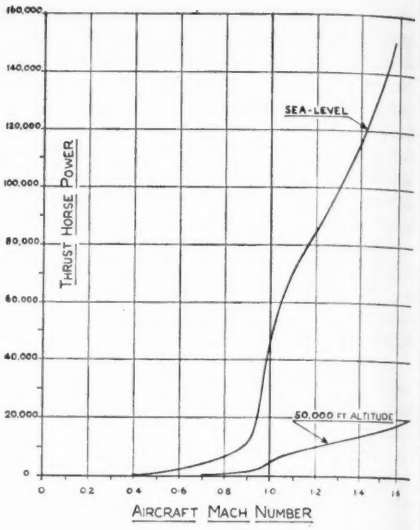


Fig. 5.

during the time taken to apply it. Such embarrassments have occurred.

The importance of repetition in all forms of test flying cannot be too highly stressed, but it applies most acutely to this type of work. Most pilots can find examples of this in their own experience. When a succession of changes is occurring in a very short time and particularly when trouble is brewing, one point is liable to take precedence over all others in the pilot's memory. An incorrect interpretation can be placed on a certain general sensation when no hard and fast symptom presents itself. Such things as stick position may not have been clearly noted, or may even be reported incorrectly, due to unusual forces. This is one illustration, but there are many, of the necessity for repeating any particular phase. It may be possible to repeat at once but if any doubt exists it is often worth while waiting until a more clear, concise, idea of what is happening, can be provided by thought and discussions on the ground. There is probably no single aircraft about which conflicting reports have not been given concerning the same behaviour.

REQUIREMENTS FOR RESEARCH AIRCRAFT

It obviously follows from this that improved means of recording are necessary and in fact this is one of the chief

requirements at the present time. Auto-observers have been used for some time but the pressing need is for continuous transmission of all instrument readings. This entails a vast amount of work in sorting out the wheat from the chaff in the reduction of results but it means that no change, however small, passes unnoticed and that in the event of an accident there is complete knowledge of the circumstances leading up to it.

Continuous speech recording is a step in the right direction but until the perfecting of a telemetering system is complete, the responsibility for missing nothing rests with the pilot.

In referring to recorders one of the requirements for future high-speed research work has been mentioned, and there are other vital needs for future aircraft.

From the preceding remarks it is clear that the biggest deterrent to a pilot investigating aircraft behaviour is to find himself in a dive. It is essential therefore to have sufficient thrust to negotiate the transonic region in a climb. This not only provides a bigger margin of safety in cases of violent nose-down trim changes and control ineffectiveness, but provides a greatly improved deceleration which has been seen to be very important, particularly under conditions of high I.A.S. It should be remembered that, from the point of view of aeroelasticity and its allied troubles, high I.A.S. means speeds in excess of 450 to 500 m.p.h. A Mach number of 1.0 at 30,000 ft. is 450 m.p.h. I.A.S. so that even moderately high altitudes will produce effects which have hitherto been connected with the sea level to 15,000 ft. region.

The first requirement then is vastly increased thrust. A recent paper by Owner and Hooker[1] gave some interesting figures of thrust needed for level speeds of $M=1.0$, in contemporary fighter and research aircraft. At the present stage of development of gas turbines a rocket motor seems to be essential for this work. There does not seem to be any immediate hope of increasing gas turbine thrust three to four times, which is the sort of figure required. The American Bell XS-1 has proved the tremendous advantage of high thrust. In spite of very short endurance, a steady and complete test was made at transonic and supersonic speeds on almost every flight.

Larger air brakes should be included with any increase in thrust and this requirement is equally important in combat aircraft where rapid changes in speed are necessary. The necessity for air brakes of tremendous power follows from the previous mention of steep dives, should such a state of affairs occur with insufficient control.

Reference to the Bell XS-1 leads to an important point in considering high speed research aircraft of the future. In the past, all aircraft have been built to operate in a conventional manner from limited airfields. For pure research machines and possibly, eventually operational aircraft, considerable increases in performance could be expected if landing speeds were allowed to rise and new steps taken to decelerate the aircraft on the ground. Even more unconventional methods apply equally.

Contrary to popular belief, there is a greater degree of safety in flying such an

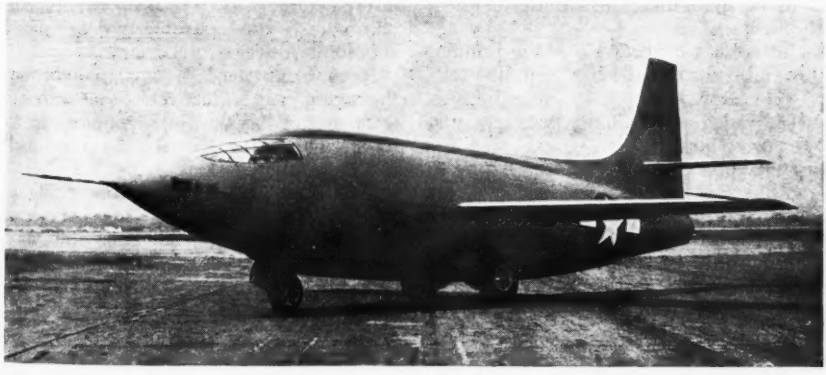


Fig. 6.
The Bell XS-1.

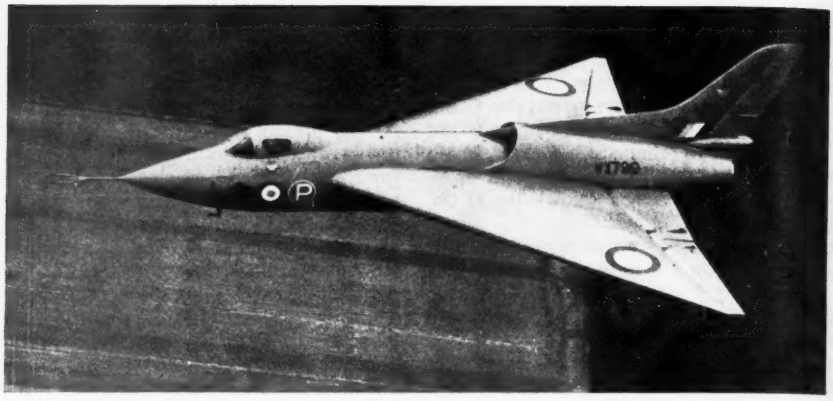


Fig. 7.
The Avro 707B experimental delta aeroplane.

aircraft to transonic or supersonic speeds than more conventional aircraft which have not been designed with that end in view.

Further requirements, the success of which has been seen already, are power boost controls and movable tailplanes or stabilisers. As already stated, power boost controls require new techniques of flying and testing, particularly when irreversible. Their use appears to be doubly important in view of flutter experience.

The moving tailplane is essential to provide the degree of trim necessary, at the same time overcoming ineffectiveness. Incidentally, incidence changes on the tailplane have been found to influence other characteristics such as buffet, and also to allow varying elevator angles to be used under otherwise identical conditions.

No aircraft has exceeded a Mach number of 1.0 in full control without a trimming tailplane. On the D.H. 108 no investigation beyond $M=0.88$ would have been possible without power boost.

The stick forces which a pilot is happy to cope with seem surprisingly low, but his position in relation to the stick, combined with the psychological differences between pulling and pushing, must be remembered. Morgan, of the R.A.E., in a paper on stability and control[2] presented a table which gave a very fair idea of this problem. Thus the most a pilot likes to hold is 20 lb., although if worried he may hold 100 lb. for a short time. Research aircraft should have controls which can be deflected to their limit stops under any conditions. This means that the pilot could break the aircraft quite easily, but in the interests of trim changes and ineffectiveness such considerations must not be allowed to cloud the issue. Operational aircraft, in this respect, differ from the research types, but various forms of g restrictors are being developed which will provide a good compromise between safety and manoeuvrability.

The future should provide a more straightforward approach to the speeds which are now obtained under the most disagreeable circumstances. Naturally any aircraft to reach its maximum obtainable speed in the supersonic region will have to be dived. But given the big increase in thrust mentioned, the intervening region where behaviour is unpredictable will have been negotiated in a climb and the extreme safety measures should no longer be necessary.

Recent experience seems to indicate that the worst pains are over. The unfortunate decision to delay development of a supersonic research aircraft in Great Britain has had far-reaching repercussions.

The unrealistic ideas concerning pilot safety arose not so much from the absence of knowledge of transonic behaviour, as from an incorrect appreciation of what the pilot can cope with in an unconventional aircraft, particularly in relation to take-off and landing.

Although to some extent small airfields are a limiting factor, considerably more progress could have been made in the transonic field by piloted aircraft.

The result of failure to go ahead has resulted in the type of test work described earlier. Ironically, the risk involved has been far higher than would otherwise have been so. Reports of flights on the Bell XS-1 leave no doubt on this matter.

It is to be hoped that lost ground will soon be recovered with these mistakes left behind, and there is no doubt that this country can lead the world in this field. There is a tremendous store of keenness among pilots and scientists. It remains for those in control to use it fully.

A word about tailless aircraft and the pilot would not be out of place. There has been a fierce controversy in this and other countries over the tail. Pilots' impressions of tailless aircraft have, in general, been unfavourable, but it is worth examining the evidence. Unfortunately, there have been several accidents to tailless aircraft and there is no doubt that under certain conditions of low and high speed there are several problems to be solved. Unfavourable conditions arise mainly from a lack of damping in pitch, rather sloppy controls at low speeds and high angle of attack on the approach. These are not solely high speed aircraft problems but they are mentioned to show the reasons for the pilots' apathy to this type of configuration.

To set this in its true perspective the credit side must be viewed. The D.H. 108, which was similar in appearance to some German designs, first flew in 1946 and had a level speed performance which in 1950 was still equal to, or greater than, any other aircraft flying in Great Britain—with 30 per cent. less power. It is still the only aircraft in Great Britain to have exceeded a Mach number of 1.0 although it was only in full control up to $M=0.98$. No case of buffeting has been experienced on a tailless aircraft at high Mach number. The true tailless configuration has now been developed into the delta plan form. Several of these aircraft are now flying.

In view of the aerodynamic and structural advantages of this type it is to be hoped that the handling qualities and impressions will be superior to the old tailless configuration.

In all this it must be remembered that in approaching supersonic flight pilots will have to accept new standards. Some are already accepted. Therefore unfavourable impressions should not be too readily accepted at an early stage.

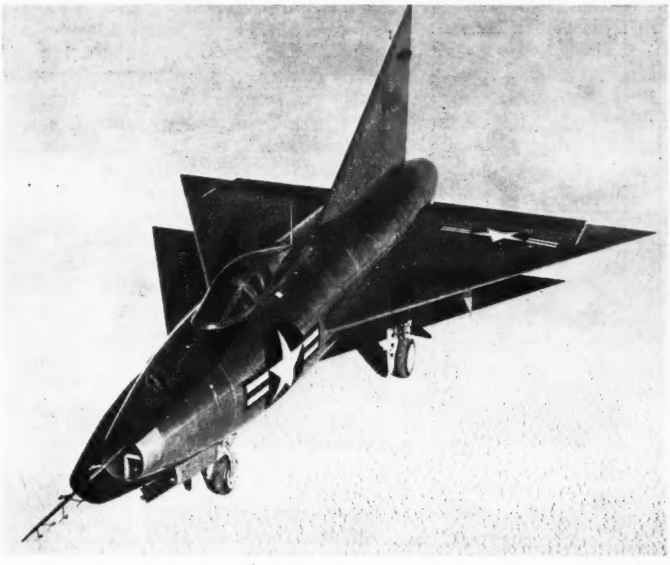


Fig. 8.
The Consolidated Vultee XF-92A experimental interceptor delta aeroplane.

SAFETY MEASURES

The pilot safety factor is increased by various means of protecting the pilot from indirect effects of high speed. *Indirect* because there is no physical effect from simply flying fast in a straight line. At 40,000 ft. where I.A.S. is low, there is no impression of speed, and at low altitude, but for air noise or the view of the ground, the passenger has no way of judging his speed in smooth air. The physical effects come from normal acceleration, measured in units of gravity or *g*'s and from the low atmospheric pressure at high altitude. Turns and pull-outs give steady values of positive *g*, while bumps or oscillations of the aircraft controls give a sharp rise and fall in *g*, both positive and negative. This latter effect is uncomfortable and, due to lack of headroom and so on, may cause injury but, being instantaneous, has no effect upon the blood stream. Sustained *g*, however, causes the blood to flow away from the head and the heart is unable eventually to maintain sufficient pressure, resulting in temporary blindness and finally unconsciousness. Blacking out, as the initial blindness is called, occurs at 4½ to 5 *g* after 6 to 8 sec. on the average man. Recovery is almost immediate on reducing *g* but the accumulative effect of many applications of *g*, such as in combat or aerobatics, is fatiguing. Unconsciousness occurs only if further *g* is applied after the pilot has completely blacked out. This is a most unlikely contingency.

For some years before the 1939-45 War it was possible to black out at low altitudes.

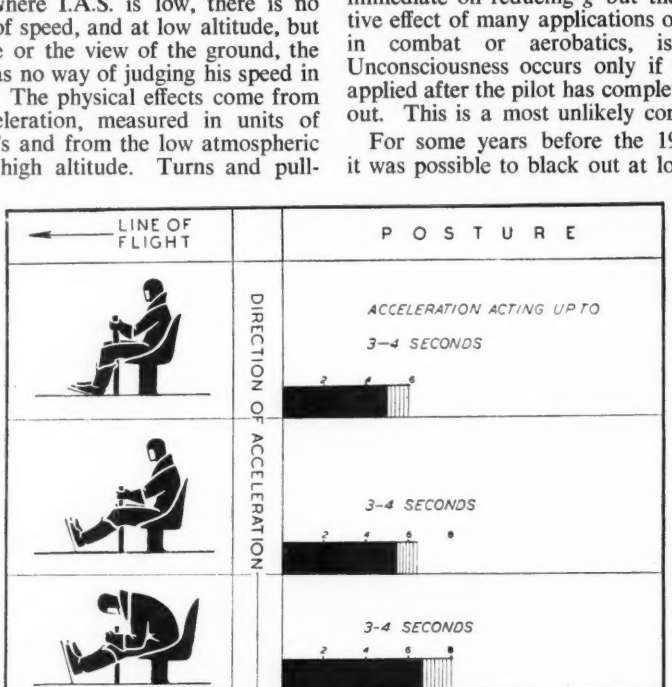


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Fig. 9.
Effect on posture on blacking out.

The Schneider Trophy race was an example of this in 1930. Only recently, however, has it become possible to black out at quite *high* altitude. This is due partly to the increase in indicated speeds possible at high altitude, but more particularly at high Mach numbers, to the improvement in maximum lift with Mach number allowing stalling *g* equal to.

or in excess of, "blacking-out g" above 30,000 ft. It is essential now, therefore, to provide g suits for work on research aircraft and, in the near future, for fighters as well. The g suit inflates with air under g, squeezing the legs and stomach and preventing the blood from pooling. It also gives support to the stomach. A very uncomfortable feeling in the pit of the stomach can be produced by g combined with high altitude due to a form of air lock. The chances of this are reduced by the suit.

Negative g has not given rise to much trouble since it is rarely experienced unintentionally. However, as described earlier, the author was subjected to $-3g$ in the D.H. 108 for several seconds and up to $-4g$ instantaneously in a Vampire. This is considered the limit which can be withstood without such unpleasant effects as eye blood vessels bursting ($-3g$ and over causes small white flashes before the eyes and beyond this a red-out occurs). It seems possible, however, in the light of development of rocket powered aircraft with vertical climbs and so forth, that it will be necessary to apply negative g more frequently in the future. If so, a remedy for the effects is essential. Negative g is much more uncomfortable and *demoralising* than positive. A well fitting, tight harness, is vital. This applies in bumps and oscillations when sharp increments of g are applied. Strapping-in well cannot be over-emphasised for high-speed flying.

A discussion of high speed is not complete without reference to physical problems at low atmospheric pressures, since it has been shown that all high-speed investigation starts under such conditions.

Until quite recently there was a curious idea that test pilots were in a better position to suffer the discomforts of very low pressures than their Service companions. In consequence, even now, some research machines have no pressure cabin.

The maximum altitude that can be withstood in reasonable comfort with no pressure cabin and a normal oxygen mask is 42,000 feet. Unconsciousness will occur at 45,000 ft. after a short time. The use of a pressurised mask and waistcoat increases these limits to 44,000 ft. and 47,000 ft. However, morale becomes extremely low under these conditions and sometimes the pilot climbs up bent on carrying out a full programme to find himself curiously apathetic to the whole affair and even losing height without pressing on to the extent planned. This state of affairs, although obviously most unsatisfactory, was tolerated in the absence of pressure cabins. But now that the ceiling of fighter and research types has risen well beyond 45,000 ft. the pressure cabin is vital to the success of the aircraft. This means that devices such as pressurised masks or pressure suits are only used in emergency when the cabin pressure fails. In the event of this happening the pilot is subjected to rapid decompression or a height change of 30,000 ft. in about one second. At the heights being discussed the immediate effects of decompression are not serious, but bearing in mind what has been said concerning maximum heights without pressure it is obvious that, if at 47,000 ft. or above, there is only a very short time in which to descend to a safe height. The pressure mask and waistcoat permit failure at 50,000 ft. provided that a descent is started within 10 or 15 seconds. Above this height a full pressure suit is needed to provide for an emergency. The pressure suit which covers the whole body will permit a pilot to be exposed to an almost infinitely low pressure. When this type of apparel is fully developed the worst problem of the altitude aspect will be over.

On this question most harmful statements have been made in various Press articles. It is a problem which, if respected, can be safely negotiated.

At all heights and under any condition it may be necessary and must be possible to abandon the machine. The author has never had this experience and is therefore unqualified to discuss it at length, but all pilots have strong views on the subject. It is physically impossible to bale out without assistance at speeds of over 500 m.p.h. and, except through nothing less than a miracle, the chances of getting clear away from an aircraft at 400 m.p.h. are remote. These speeds are, of course, indicated air speed, since this is the measure of air *force* which will be experienced. It is possible to get clear at 600 m.p.h. at 40,000 ft. when I.A.S. is only 300 m.p.h.! Obviously then it is extremely desirable to be ejected from modern aircraft which are flying in excess of safe "baling-out" speeds almost all the time. At present, in some cases, 550 to 600 m.p.h. aircraft are being used without ejection seats, but all future designs will have some means of

Fig. 10.
The Douglas D-558-2 research aeroplane with jet-assisted take-off (JATO) and gas turbine and rocket motor for high speed.

freeing the pilot mechanically from his aircraft.

The ejection seat has been used both in experiment and emergency and has proved itself very successful. However, all live ejections have been made at speeds considerably below the present capabilities. The fastest live ejection was made experimentally at a *true* speed of 505 m.p.h. This represents, however, an indicated speed of less than 450 m.p.h. at the height at which the ejection was made. Since speeds up to 650 m.p.h. indicated have been reached in this country and up to nearly 700 m.p.h. indicated in the United States, it is apparent that a vast increase in safe ejection speed is necessary. It seems unlikely that the tremendous effect of air loads on the human frame when exposed at 600 m.p.h. and over will allow the use of the ejection seat, eventually requiring a detachable cockpit or fuselage section, which will be decelerated before the pilot leaves it, either manually or by further ejection. This method is applied to the Douglas series of high speed research aircraft, the D-558-1 and 2 and, although untried in practice, would appear to be quite straightforward provided that there is sufficient height in hand and some form of stabiliser for the detachable portion. It is fairly certain that there can never be any completely satisfactory means of leaving an aircraft at very high indicated speeds below, say, 3,000 ft. There are plenty of miraculous escapes on record, particularly during the war, at all kinds of heights and speeds, but they are, nevertheless, the exception, and cannot be allowed as evidence in making the decision concerning methods of abandoning aeroplanes.

Baling out at high altitudes means low or moderate indicated speeds, but requires emergency oxygen and a delayed drop to 15,000 ft. or so before opening the parachute. At altitudes above 20,000 ft. damage to the parachute may result from the higher terminal velocity attained by a body. It is an advantage, anyway, to drop to 20,000 ft. as quickly as possible to avoid discomfort from cold. A portable oxygen bottle is now always carried on the parachute. Development work on high altitude baling out has recently resulted in an automatic ripcord operated by an altitude switch. It is then simply a case of waiting! All development in this field must lead to the jettisoning of a compartment which rapidly decelerates and which maintains pressure and contains oxygen supply.

TEST PILOTS

Much nonsense has been heard and talked of in the past about test flying, but few people outside the actual design teams have much idea of the requirements of a test pilot. In dealing with high-speed research, particularly, where the smallest change of trim or barely perceptible stick movement may tell a whole story, it is essential for the pilot to have a sound knowledge of what is actually happening to the various parts of his machine under all conditions. The author considers it essential to have an overlapping in the spheres of knowledge of pilot and scientist. This may suggest agreement with recent suggestions that fully trained aerodynamicists or engineers should be converted to test pilots, but this appears to be the wrong way to do it. A considerable amount of theory should be understood by the pilot and he should be trained in it. That is precisely what the Empire Test Pilots' School course

is doing, and doing extremely well. After such a training it is up to the pilot to maintain an up-to-date knowledge of all theory that concerns his work. The specialised problems of mathematics and engineering are not required by the pilot. He and the scientist must speak the same language but not necessarily the same dialect.

The test pilot must be first and foremost a pilot, with the necessary temperament and keenness on flying itself. In the air he must be determined and patient. He must try everything more than once. Many convincing examples have been experienced of the false impressions which can be registered when several things are happening in a very short space of time. Such incidents must be repeated until they can be fully analysed by pilot and auto-observer results. Contrary to popular opinion, the test pilot must possess a good fear! As an experienced test pilot of the past said, "fear is the pilot's governor." A complete absence of fright will result in poor test results and often in catastrophe.

It is important that he should keep as closely as possible in touch with similar types of work, not only throughout the country, but the whole world. Rivalry between firms and national security have to be respected, but exchanges of information and experience between pilots is tremendously valuable. The pilot must always be up-to-date in his particular field, both on the practical and theoretical side.

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DISCUSSION

K. G. Rendle (*Graduate*): What would the author regard as a dangerous landing speed?

Squadron Leader Derry: There was no difficulty in landing an aeroplane fast, provided that there was an unlimited length of run; the Americans had runs of 12 or 13 miles. It was true to say that it was much easier to land an aeroplane fast than slowly, at stalling speed, if the undercarriage and tyres were strong enough; indeed, inexperienced pilots could be seen landing much too fast because it was easier than to land slowly. There was nothing at all in touching down; the whole problem depended on means of stopping the aircraft after it had touched down.

Brakes were inadequate to cope with much higher landing speeds than were normal today. He was not criticising them, for they were extremely good for the job they had to do at present. The tyres also would not withstand much increase of landing speed although without the use of brakes they would withstand quite a lot more than with brakes. There were such things as the tail parachute which had been seen operating on the Avro Delta and gave reasonable deceleration which should effect a 30 per cent. reduction of landing run. Again, the use on aerodromes of arresting wires, such as were used on the decks of aircraft carriers, was a possibility.

Thus it was difficult to estimate what might be considered as the maximum landing speed, but given a suitable aerodrome, it was possible to land quite happily at 200 m.p.h.

A Speaker: At what Mach number did flutter occur, and how was it stopped when once it had started?

Squadron Leader Derry: There was no positive way of stopping it, once it had started. It would stop itself, however, if one decelerated quickly enough; in the paper he had mentioned one serious case of flutter, and that was stopped by decelerating.

As to the Mach number at which flutter occurred, there was a damping loss in the D.H. 108 at a much lower Mach number, but it eventually became negative at high indicated air speeds at a Mach number of about 0.87 or 0.875. It was possible to fly at 0.87 with zero damping, but an increase of 0.005 would exceed the limit. Zero damping could be tolerated for research purposes if the point at which it would become negative were known. It was not satisfactory to accept zero damping except for limited investigations. It must be avoided if any further use were to be made of the aeroplane.

D. J. Adams (De Havilland Technical School): Could the author throw any light on the D.H. 108 crashes?

Squadron Leader Derry: He was unable to say much about them, because the results of

the enquiries had not been published. He would like to see the results published officially, because there had been a lot of doubt about the causes, and that had given the aircraft an unnecessarily bad name. The fact that tailless aircraft had crashed had gone against them; there were a lot of things to get right, but the aircraft were not so bad to fly and they could give a magnificent performance—he was talking of high-speed aircraft, and did not wish to become involved in the transport argument.

P. T. Fink (*Graduate*, Imperial College): Would the author give an opinion on the nature of the artificial feel which a pilot would like to be given in aeroplanes which had irreversible power controls.

Squadron Leader Derry: He had not flown with fully irreversible controls. One could not get feel back from irreversible control; feel could only be produced by means of a spring, and it was difficult to arrange without involving a too positive neutral position, so that an unnatural force was needed to initiate a movement. Artificial feel brought about a different technique of flying. The first thing that was inclined to result was flying on the trimmer.

In this connection doing away with the trimmer would be a good step forward. The old form was a wheel, and the latest form was a switch on the stick to operate the movable tailplane. The ideal would be a fully trimming device working off the stick, which meant that the aircraft would trim itself. But that stage had not been reached yet.

Mr. Irving: How was stability affected by inequalities such as walking over wings when wearing hobnailed boots? He also invited comment on the problem of damping loss.

Squadron Leader Derry: The cause was not known exactly so it was difficult to give an answer. He felt that the chances of repeatability were fairly good in the case of the D.H. 108, because the wing was not a laminar flow wing and small changes of section should not be expected to make much difference. There might be small local differences, but they would not amount to much at the Mach number at which loss of damping occurred. But there were cases of poor repeatability, as, for example, the Vampire; one Vampire varied a good deal from another at high Mach number, although not in a sense which would cause any serious trouble, there being small changes in hinge moment, stick force and the feel of the elevator.

One particular characteristic which was very critical to something—it was hard to tell what—was the wing drop. Production aircraft, some of which suffered wing drop at high Mach number did not repeat at all well; one wing would go on one flight and the other wing on the same aircraft would go on another flight. That was obviously very critical, and the whole thing was dependent on small changes in yaw and possibly changes in profile. There was experience of wing drop on all aircraft; but it did not always repeat.

Stalling on high speed wings was another problem. There must be very small changes in the profile of the wing, for they were cured by putting on the thinnest possible application of filler.

Mr. Dynall: Was it the author's opinion that dog-fighting was likely to occur again in the future, and what was the effect of it on the pilots?

Squadron Leader Derry: If two fighters were in the air and were shooting at one another, there was bound to be some sort of dog-fight. The idea that there would not be any more dog-fighting had resulted rather from the thought that that state of affairs would not arise so much in the future, that fighters would be escorting a bomber and would stay with it, or that they would be attacking a bomber and would not bother with the escort, so that there would not be big fights between fighter forces. He believed there would be dog-fights in the end, but they would occupy much more space than formerly, for with higher speeds the aircraft would have to travel greater distances to turn round. They would also occur high up, for dog-fights could not be prolonged in a jet at fairly low altitude; if an enemy wanted to get away he would then climb and, if he were caught, he would be caught at high altitude. Probably there would be less tendency to turn and more tendency for one man to use his higher critical Mach number or higher limiting Mach number, if he thought he had got it, and he would get away in a dive while his opponent was turning inside out in the effort to catch him.

A Speaker: Would there be any difficulties in flying supersonic aircraft?

Squadron Leader Derry: There would be difficulties and pilots would have to get

accustomed to new methods of flying. One of the arguments about the tailless aircraft was that it was not a normal aircraft and that it behaved in an unusual way. But pilots must become accustomed to aircraft behaving in an unusual way, and one of the problems would be to get used to different behaviour at high speeds, and particularly to an altogether different feel of the controls.

The biggest problem perhaps of supersonic aircraft would be to fly at subsonic speeds, and particularly at the comparatively low speed of landing. The landing speeds were bound to increase; but the present trend to low aspect ratio with sweepback was not as bad as all that for landing speeds. The delta wings illustrated had quite a low wing loading. There were other reasons for higher landing speeds, but he did not think that anything above 200 m.p.h. would have to be accepted. That might horrify some people, but he did not think it should. Certainly a new set of rules for the air must be found, because the aircraft would not be able to cruise around at low speeds. From his little knowledge of the theoretical research which had been going on, there should not be a great deal of difficulty in flying at high subsonic speeds. Apart from cruising conditions, he felt that the whole idea of having to poise oneself at about 0.9, take a deep breath and rush madly through to 1.5, or whatever it was, was quite false. The aircraft would not be able to cruise in the transonic region; it would be either supersonic or subsonic. But from the research point of view there was not much doubt, particularly from what the X-S1 had done, that the change from subsonic to supersonic speeds could be quite gradual. It depended on the trim changes, among other things; but in any aircraft, however well designed, there was bound to be a trim change. There was no reason to suppose that it would be better to encounter the transonic region in a rush than to do it gently.

A. C. Campion (*Graduate*): Had the author seen flying saucers?

Squadron Leader Derry: He had not; but he had seen an interesting thing which might have led many people to believe that they had seen flying saucers. It was a shooting star; viewed from the very high altitude at which he was flying, and apparently because of the rare atmosphere at that height, the star seemed to be much bigger than it would look from the ground. Although he was not much nearer to it than when on the ground, relatively speaking, it had looked surprisingly big, and quite close.

J. Wingate (*Student*, Fairey Aviation Co.): Was there any marked change in the noise of the engine when flying at about the speed of sound and was there any danger resulting from the noise?

Squadron Leader Derry: He felt that the speaker was perhaps confusing what were called ultra-sonic effects from high frequency engine noise with supersonic aircraft speeds. The noises in aircraft came through the aircraft, where the air was pretty well stationary, so that it was unaffected. He had heard stories that pilots had sometimes encountered suddenly a curious silence, but he could not understand that, because the propagation of the sound waves from the outside of the cockpit to one's ear was through air which was stationary, or very nearly so.

The noise from jet engines was not so great as at first expected. Nevertheless, it was a good thing to wear helmets and to protect the ears, not only in order to pay attention to the radio, but because it could be shown medically that continued flying with the ears exposed to sound would gradually reduce hearing.

POWER PLANTS FOR HIGH-SPEED AIRCRAFT*

by

A. D. BAXTER, F.R.Ae.S., M.Eng., M.I.Mech.E.

INTRODUCTION

A few years ago when high-speed aircraft were mentioned, speeds of 300 to 400 m.p.h. came to mind. The advent of jet propulsion has made those figures 100 per cent. out of date and today speeds are discussed more and more in terms of Mach number; for example, high-speed subsonic aircraft fly at Mach numbers of 0.85 to 0.90, aircraft are flying in the transonic region and supersonic guided missiles are proposed for speeds anywhere between $M=1.5$ and 2.5, *i.e.* ground level speeds up to 2,000 m.p.h.

It is proposed to review very broadly the suitability of propulsion units for these transonic and supersonic applications. What is the difference between ordinary power plants and those for high speed? The answer might be contained in another question—why are supersonic aircraft different from conventional types? The aerodynamicist will give an involved explanation concerned with compressibility, drag rise, shock waves, and so on. That may be quite correct, but the fact of the matter is that the aerodynamicists still have a lot to learn about transonic problems and so the engineer is called upon to supply enough brute force to make up for their ignorance. The brute force must, however, be confined in a small space and that is the real point of the supersonic power plant. It might be added that all the ignorance is not confined to the aerodynamics side of high-speed flight and there is no doubt that the engineers still have a lot to learn.

* A paper read before the Chester Branch of the Society on 17th January 1951.

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NOTATION

M = Mach number
T = thrust
D = drag
C_D = drag coefficient
C_T = thrust coefficient
S = wing area
A = power plant frontal area
V = forward speed
ρ = ambient air density
m = jet exhaust gas mass flow rate
v = exhaust gas velocity
T_4 = absolute gas temperature in jet pipe
P_4 = absolute gas pressure in jet pipe
P_5 = atmospheric pressure
γ = ratio of specific heats

POWER PLANT REQUIREMENTS

For an aircraft to maintain level flight at a given speed, or accelerate, it must have a power plant giving a thrust T equal to, or greater than, the drag D of the aircraft,

i.e. $$T \geqslant D.$$

Another way of expressing it is in terms of thrust and drag coefficients:—

$$C_D = D/(\tfrac{1}{2}\rho S V^2)$$
$$C_T = T/(\tfrac{1}{2}\rho A V^2)$$

If $$T = D$$
$$C_T = (S/A)C_D.$$

In Fig. 1 these relations are drawn diagrammatically against Mach number. It is not claimed that these curves are accurate, but they do illustrate the trend. Thrust curve 1 cuts the drag curve at a relatively low speed and is typical of the normal subsonic power plant. Curve 2 crosses the drag curve at three points, indicating that while thrust may be less than drag in the transonic region, it can be greater over a certain range of

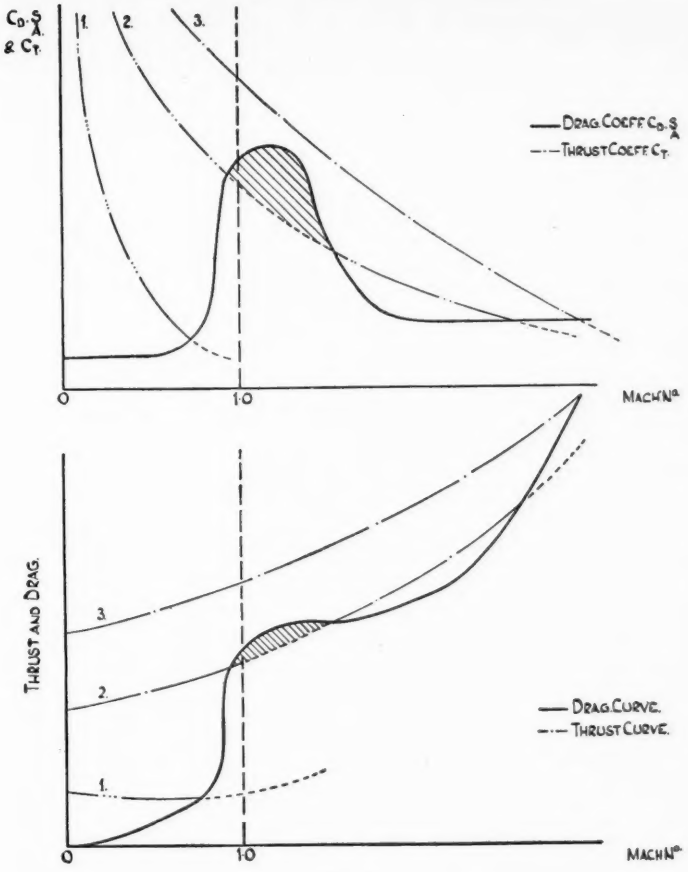


Fig. 1.
Relation between thrust, drag and speed.

supersonic speeds. An aircraft with a power plant having such a characteristic could not achieve supersonic speeds in level flight, but might do so in a dive through the transonic range, followed by level flight. A number of present day engines have this type of characteristic, but cannot be truly termed supersonic power plants. Curve 3, however, gives positive $(T-D)$ values at all speeds up to high values of Mach number and should be the objective of all supersonic power units.

The main types of engine are:—

(*i*) reciprocating engine
(*ii*) gas turbine
(*iii*) ram jet
(*iv*) rocket.

RECIPROCATING ENGINE

As an approximation, the piston-engine power may be considered as independent of speed. Thus

$$\text{power} = \text{constant}$$

or $$T \times V = \text{constant}.$$

Therefore $$T \propto 1/V$$

and $$C_T \propto T/V^2 \propto 1/V^3.$$

As V increases to high values, propeller efficiency falls and hence the thrust power falls. From this it is apparent that C_T falls even more rapidly than $1/V^3$. An increase in engine shaft power will increase the thrust, but this usually entails an increase in frontal area A and consequently no great improvement in T/A or C_T results.

The best present day reciprocating engine figures are given in Table I.

TABLE I

RECIPROCATING ENGINE PERFORMANCE

Engine	*Power P* (*h.p.*)	*Frontal area A* (*ft.²*)	*P/A* (*h.p./ft.²*)
Centaurus	2,800	17.6	160
Sabre 7	3,000	13.2	227
Eagle	3,500	15.1	231

Assuming a propeller with an efficiency of 100 per cent. at 600 m.p.h., the best thrust/frontal area ratio that could be achieved would be 144 lb./ft.^{2} In fact the propeller efficiency would be a long way from this ideal and the thrust correspondingly lower. That such engines are unsuitable for very high speed flight will appear more clearly when their performance is compared with the other types.

TURBINE ENGINES

The gas turbine as a power plant can be used either as a turbo-jet or as a turbo-prop engine. The latter gives a somewhat better shaft horse power per unit frontal area than the piston engine and also has some residual jet thrust available. It suffers from the propeller efficiency losses at high speeds and can be dismissed from consideration for that reason, but it is of interest to note some performance figures (Table II) for comparison with piston engines. These are sea level static figures, but can be assumed, as an approximation, to be the same at high speed. It will be noted that the best figure is equivalent to only 345 lb. thrust/ft.^{2} at 600 m.p.h., even with a propeller of 100 per cent. efficiency.

TABLE II

TURBO-PROP PERFORMANCE

Engine	*Power P* (*h.p.*)	*Thrust T* (*lb.*)	*Frontal area A* (*ft.²*)	*P/A* (*h.p./ft.²*)	*+ T/A* (*lb./ft.²*)
Mamba	1,320	405	4.6	287	88
Naiad	1,500	240	4.25	353	56
Proteus	3,200	800	8.1	395	99

The turbo-jet is a great improvement over propeller engines for high-speed flight. This is partly because it develops approximately constant thrust with varying flight speed. Actually thrust falls at first due to the intake momentum drag increasing, but later begins to rise as the effect of ram pressure becomes noticeable.

At low speeds its thrust/frontal area ratio is still a long way below that of the piston engine, but as the speed rises, the thrust of the latter falls rapidly and a cross-over occurs. At high forward speeds the jet is a great deal better, but in general the intersection of its thrust and drag curves is still well below $M=1.0$.

In Table III a few typical thrust figures are given. It will be noted that recent units have doubled the output per square foot of frontal area and that the axial compressor engines are far ahead of the centrifugals.

TABLE III

TURBO-JET PERFORMANCE

Engine	*Thrust T* (*lb.*)	*Max. dia.* (*in.*)	*Frontal area A* (*ft.²*)	*T/A* (*lb./ft.²*)
Derwent V	3,600	43.0	10.1	355
Nene	5,000	49.5	13.4	375
Beryl	3,850	38.0	7.9	490
Sapphire	7,200	35.2	6.8	1,050
Orenda	6,500	39 (approx.)	8.3	780

There has been a lively discussion* recently on the relative merits of the two types, but for very high speeds there is no doubt that the axials are preferable. They have achieved thrusts of more than 1,000 lb./ft.^{2} at sea level, which is a figure often suggested as the objective for supersonic power plants. Now that this figure has been achieved with turbo-jets, supersonic flight is undoubtedly closer at hand, but the target appears to have retreated somewhat.

TURBO-JET THRUST BOOSTING

Even with present advances level flight at $M=1$ and above is still not possible. Some improvement can be obtained by boosting the thrust without increasing the frontal area. The engine thrust is given by

$$T=mv/g,$$

and can be increased by increasing either m or v. The first can be achieved by injecting water, alcohol or other suitable fluid into the air at entry to the compressor. The evaporation reduces the air temperature and

*The Relative Merits of Centrifugal and Axial Compressors for Aircraft Gas Turbines. E. S. MOULT and H. PEARSON. *Journal of The Royal Aeronautical Society*, March 1951.

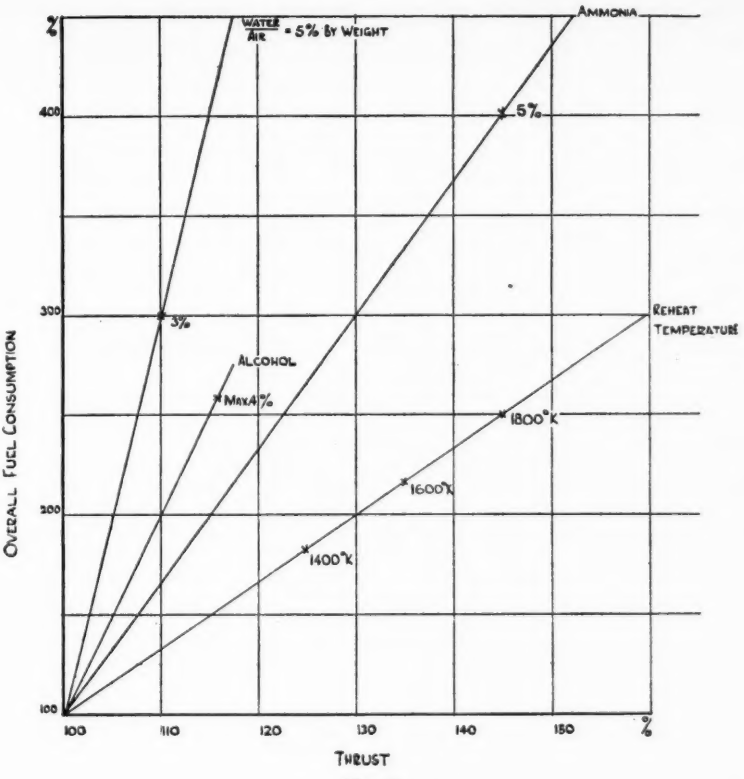


Fig. 2.
Jet engine boosting.

increases its density. Hence a larger mass of air enters at a given engine speed and the thrust is increased in proportion.

There is an early theoretical limit to this method. If alcohol were used, it would act as a fuel when it reached the combustion chamber and so less normal fuel would be injected (otherwise the combustion temperature would rise too high). Ultimately a condition would be reached when no fuel would be injected in the chamber and the alcohol would supply sufficient heat to raise the gas temperature to its limit. When this occurred the thrust increase would be about 15 per cent.

Ammonia is also a fuel which could be used. It has a high latent heat and a low calorific value. The former gives additional cooling to the air and the latter means that the rise in combustion temperature can be less for a given weight of fluid injected. In this case the thrust might theoretically be increased by 50 per cent., but practically there are many difficulties and objections. They include the risk of the fluids contaminating oil feeds, causing corrosion of the materials of the engine and producing explosions in the compressor.

Such increases in thrust are not made without penalty and expensive increases in fuel consumption result. In Fig. 2 the gross fuel consumption (intake injection plus combustion chamber injection) is plotted against increase in thrust on a percentage basis. The ratio of intake injection fluid to intake air to achieve these results is also indicated.

The alternative to increasing mass flow is to increase jet speed and this can be accomplished by re-heat (or after-burning). This consists of burning fuel after the turbine to raise the exhaust gas temperature before

passing through the propelling nozzle. It can be shown that

$$v \propto \sqrt{\left\{T_4\left[1-\left(P_5/P_4\right)^{\frac{\gamma-1}{\gamma}}\right]\right\}}$$

If pressures P_4 and P_5 are fixed, thrust varies as $\sqrt{T_4}$. Thus an increase from 900° K. (625° C.) to 1,400° K. (1,125° C.) would give 25 per cent. increase in static thrust.

In flight, the percentage thrust increase is greater because intake momentum loss is the same whether re-heat is operating or not. At 600 m.p.h. an increase in thrust from 25 per cent. to 35 per cent. could be expected.

Temperatures need not be limited to 1,400° K., but re-heat introduces various problems which become more serious as the temperature increases, as, for example, heat insulation of the jet pipe and the provision of a variable area exhaust nozzle. The latter is required because of the lower density of the gases; its area should vary as $\sqrt{T_4}$.

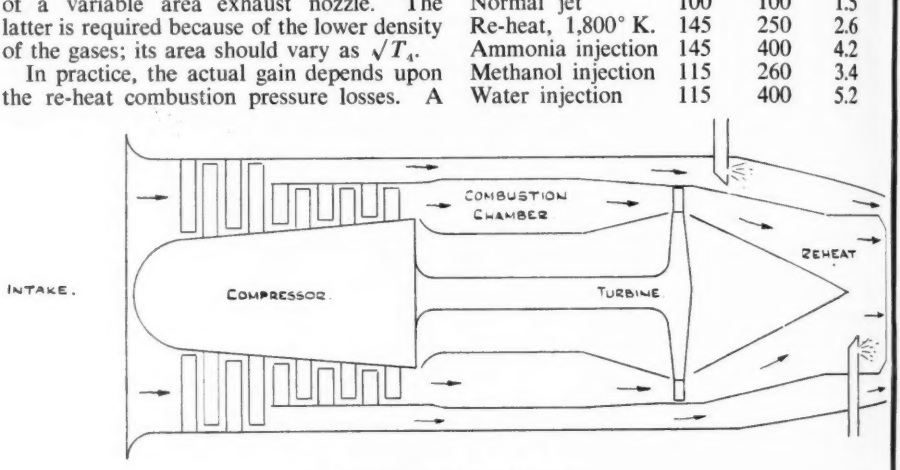
In practice, the actual gain depends upon the re-heat combustion pressure losses. A drop in P_4 counters a rise in T_4. For example, a normal jet engine operating at sea level with a loss in jet pipe pressure, due to re-heat equipment, of 3 lb./in.² would reduce the gain from 25 per cent. to 15 per cent.

The ideal gain in thrust is shown in Fig. 2 for various re-heat gas temperatures and a comparison of the maximum gains to be expected is given in Table IV, which also gives approximate overall specific fuel consumption for a speed of $M = 1.0$.

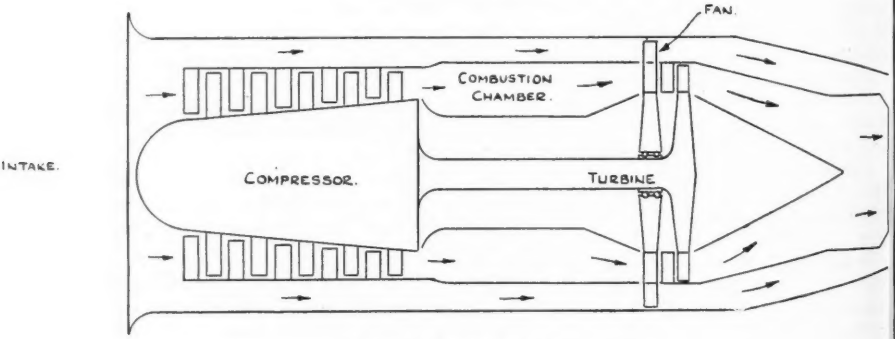
TABLE IV

COMPARATIVE METHODS OF THRUST BOOSTING

Condition	*Thrust (per cent.)*	*Fuel consumption (per cent.)*	*Specific consumption [(lb./hr.)/lb.]*
Normal jet	100	100	1.5
Re-heat, 1,800° K.	145	250	2.6
Ammonia injection	145	400	4.2
Methanol injection	115	260	3.4
Water injection	115	400	5.2



By-pass turbo-jet with reheat.



Ducted fan turbo-jet.

Fig. 3.

A further method of increasing thrust would be to over-speed the turbo-compressor by overheating the turbine gas. This would impair reliability—stress increases as the square of rotational speed and strength decreases with temperature. If used, a 10 per cent. over-speed would give 25 per cent. increase in thrust without appreciable increase in specific fuel consumption.

Another possibility which has been considered is the addition of an augmentor, in one of its alternative forms (as shown in Fig. 3), to the simple jet. This has the effect of increasing the overall air mass flow and reducing the exhaust velocity. Thus, from a given energy input, more thrust is available and a reduction in specific consumption results, but the augmentor demands a larger frontal area and the net effect on T/A is negligible.

If, however, re-heat is applied, an improvement does occur because the augmentor exhaust velocity is increased greatly. For example, without re-heat, the fan air temperature T_1 might be, say, 320° K. and the exhaust velocity v_1. With the addition of re-heat the temperature would rise to T_2, say 1,800° K., and the velocity to v_2. Then

$$v_2/v_1 = \sqrt{(T_2/T_1)}$$
$$= 2.4.$$

Comparative thrust figures are:—

Simple jet	= 500 lb./ft.²
Simple jet and re-heat	= 750 lb./ft.²
Simple jet and fan	= 500 lb./ft.²
Simple jet and fan and re-heat	= 950 lb./ft.²

This last type of engine was proposed for the Miles M.52 experimental supersonic aircraft some years ago. It was to be formed from a Whittle centrifugal engine which had the disadvantage of large frontal area.

RAM-JET

The ram-jet has been described under various titles, such as propulsive duct, Lorin duct, athodyd and even flying stove-pipe. It is a very simple propulsion unit—basically only a pipe with air entering at the front, fuel burning with it at the centre, causing hot gases to exhaust from the back at a higher velocity than the air entry velocity. The difference between the two results in a net thrust.

In practice it is not such a simple unit as this would suggest and there are still many unsolved problems. It is the logical development of the turbo-jet, although, at first sight, this is not easy to see. It can, however be demonstrated without difficulty. In the turbo-jet it is found that the pressure ratio of the compressor for maximum thrust decreases with forward speed because there is more and more ram pressure. This is shown in Fig. 4 where thrust per lb. of air flow per sec. is plotted against compressor pressure ratio. At 1,500 m.p.h. the ratio required has fallen to 1.0, that is, no compressor and therefore no turbine work is necessary. Thus, we can dispense with the rotating part and be left with a plain ram-jet.

The performance of the ram-jet is very different from the turbo-jet. First, there is no static thrust and, in fact, negligible thrust below about 400 m.p.h., even in the ideal case, but at higher speeds the thrust increases almost as the cube of the speed. Thus, at $M = 1.0$, the ideal ram-jet would give approximately 1,200 lb. thrust/ft.² of frontal area and at $M = 2.0$, nearly 10,000 lb./ft.² The practical motor depends upon the efficiencies of its components, such as the intake diffuser, combustion chamber and exhaust nozzle, and these make its thrust much lower.

In Fig. 5, ram-jet thrust coefficients are plotted against Mach number. The drag coefficient is also plotted. It will be seen that the ideal ram-jet would be a true supersonic power plant according to our early definition, but that, in practice, the curves still intersect the drag curve in the transonic range as well as at low speeds. Once beyond the drag "hump," there appears to be ample excess thrust for acceleration to very high speeds.

Thus it appears that until the ideal can be approached, ram-jets will need assistance not only at low speeds but to get through the sonic region. Actually, conditions may not be so bad as they seem. Ideas on the magnitude of the drag hump have varied from time to time, but now seem to be accepted as between four and six times the low-speed drag coefficient value. The introduction of sweepback has reduced this slightly, but its chief merit has been in displacing the hump towards the supersonic region. This is shown by the second dotted curve in Fig. 5, from which its significance is immediately apparent. The ram-jet thrust coefficient is rising so rapidly with increasing Mach

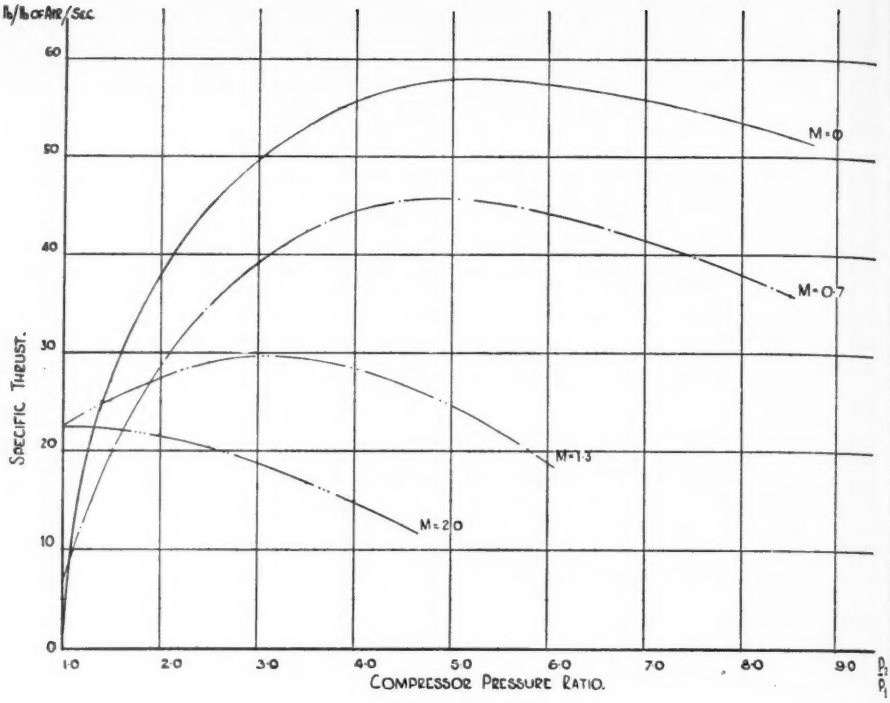


Fig. 4.
Variation of maximum thrust with forward speed and pressure ratio for turbo-jet.

number, that it is quite conceivable that by postponing the drag rise the thrust will always be greater than the drag and the motor will be able to accelerate right through the transonic range.

From the figure, it might be asked if there is any limit to high-speed flight or if we can accelerate indefinitely once the critical region is passed. Actually the C_T curves will curl over and intersect the C_D line at speeds which depend upon component efficiencies. In the ideal case this may be as high as $M=5$ or 6.

ROCKETS

Rockets are, at the moment, the only power plants that can be described truly as supersonic.

They are completely different from all the others because they carry their own oxygen and are independent of the atmosphere. They may be either solid, mono- or bi-propellant. Examples of each are shown diagrammatically in Fig. 6. For aircraft use the last is favoured. It consists of two fluid tanks, a pumping system, control system, and combustion chamber. These components can be disposed in almost any fashion provided they can be connected by pipes.

This arrangement is advantageous as the maximum use of existing fuselage and wing sections may be made. In such cases it is not surprising that the rocket motor is able to exceed the thrust/frontal area figures of all other types. At ground level there is no difficulty about achieving 3,000 lb./ft.^{2} and this figure improves with altitude as, unlike other power plants, its thrust actually increases with height—some 10 per cent. between ground level and 40,000 feet. It is the only power plant that does not ultimately lose thrust with height.

In view of these advantages it may be asked why other types are considered at all. The answer is in the rocket's chief

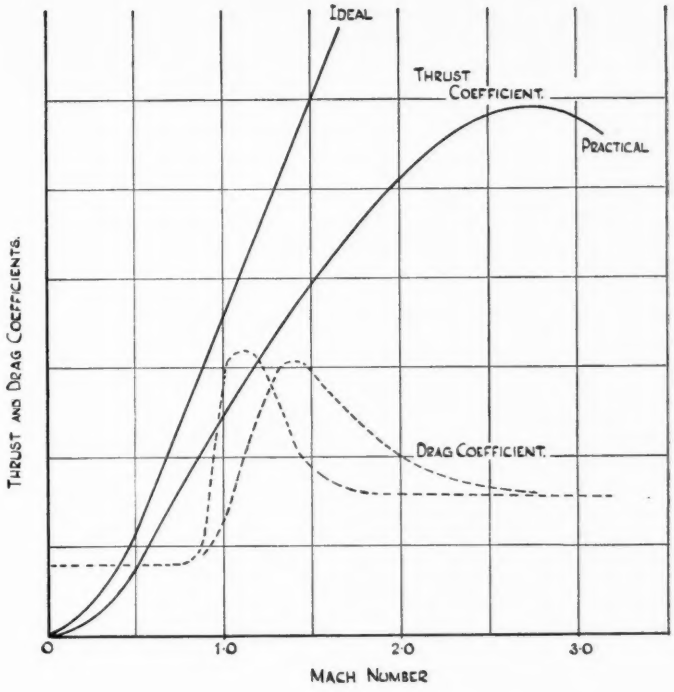


Fig. 5.
Ram-jet performance.

drawback—high fuel consumption. This is mainly caused by the need to carry its own oxygen, which more than quadruples the consumption.

The result is that consumption figures are quoted in lb./sec. instead of lb./hr. For example, the German Me 163 rocket-powered interceptor aircraft carried two tons of propellant, and at full thrust this would last for just under four minutes. By comparison, a Meteor with just over one ton and two Derwent V engines would have a sea level full throttle duration of 20 min. This enormous thirst results in fuel tankage becoming a major problem and it is liable to reduce the effective thrust/frontal area ratio. Actual specific consumptions are of the order of 18 (lb./hr.)/lb. compared with the ram-jet with 4.8 (lb./hr.)/lb., and the turbo-jet with 1.5 (lb./hr.)/lb. at $M=1.0$.

CONCLUSIONS

From the point of view of thrust alone the rocket motor is the best power plant at the present time for enabling aircraft or missiles to obtain excess of thrust over drag at all speeds from subsonic to supersonic. Fuel consumption, however, is a serious drawback to the use of this power plant.

Next to the rocket, the ram-jet shows the best thrust characteristic for high-speed flight and is likely, with improvement following research and development, to reach a stage where it can also supply sufficient thrust to be self-accelerating through the transonic range. It will, however, always require some assistance in the low subsonic speed range. It will also have a limitation at high altitudes when the atmospheric air will no longer support combustion. This applies to all power plants except the rocket. While

it pays to fly high in order to reduce drag and propellant consumption in all cases, the rocket again scores in being the only unit which does not suffer a reduction in thrust/frontal area with increasing altitude. The rocket limit is set only by the propellant consumed in the climb, which if continued far enough would use all the propellant carried. It is interesting to note that the rocket could be made to provide sufficient thrust for a vertical climb while accelerating through transonic speeds and this might prove a useful way of overcoming the stability changes which occur in this speed range.

There is undoubtedly a place for the rocket motor amongst supersonic power plants, although perhaps, in a restricted field. As an example, it might be combined with either ram-jet or turbo-jet to boost them through the critical speeds.

It is clear that propeller-driven engines are unsuitable as supersonic power plants, but there is a possibility of ducted fan turbine engines with after-burning attaining the necessary thrust output. The turbo-jet with after-burning is more likely to be a suitable engine, but in either case it is probable that the excess thrust over drag will be small in the transonic region.

ACKNOWLEDGMENT

The author thanks the Chief Scientist, Ministry of Supply, for permission to publish this paper. The views expressed are the author's own and do not necessarily reflect those of the Ministry of Supply or any other Government department.

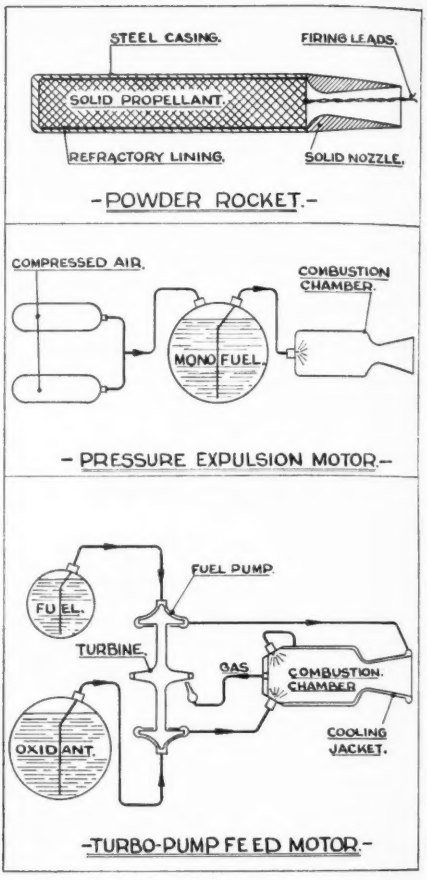


Fig. 6.
Diagrammatic layout of rocket motors.

REVIEWS

The following books are reviewed:—

Glossary of Aeronautical Terms. Part I
Source Book on Atomic Energy
Fifty Years Fly Past
Miracle at Kitty Hawk
Aircraft Design Data Book
The Principles of Air Navigation
Creep of Metals
Non-Metallic Minerals
The Inelastic Behavior of Engineering Materials and Structures
Cloud Physics
The Gas Turbine Manual
The Mathematical Theory of Plasticity
Fluid Mechanics
Thermodynamics of Fluid Flow
Displacement Pumps and Motors

GLOSSARY OF AERONAUTICAL TERMS. British Standard 185: Part I, 1950.

The task of compiling a Glossary of this kind must be a difficult one. If the Foreword is to be taken seriously, the definitions provided are to become accepted as standard in future aeronautical literature; this, surely, demands of many of them a rigour seldom recognised by common usage. The familiar term "Stagnation point" provides an example of this difficulty. The definition for an inviscid flow is clear enough: it is the point in the flow about a body at which the fluid is at rest relative to the body. It may be remarked that it is not necessarily a point on the body as the Glossary suggests (*e.g.* the potential flow past a circular cylinder with strong circulation) nor would the pressure there be a "minimum," but this obviously is a misprint. In a real flow, however, viscosity ensures that the fluid velocity at the surface of a body is everywhere zero and it then becomes necessary to refer to the dividing streamline in order to define the stagnation point. This would clearly lead to a very unwieldly statement and one's sympathies are with the compilers of the Glossary when, instead of a definition, they simply observe that the stagnation point on a body is a point of maximum pressure.

The definition of "Stagnation point" is an example of the difficulties faced by the compilers: but there are other examples, and distressingly large in number, where no difficulty exists but where an ambiguity or a restrictiveness has been introduced into the definition. There are even some definitions which unquestionably are wrong, such as that of "streamline motion"; a few, like "separation point" are quite meaningless. Serious as these criticisms may be of the contents of the Glossary, one might equally well criticise the large number of omissions. Certainly, the increased emphasis on high speed flow since the previous editions were issued appears barely to have been acknowledged. This point is illustrated by the definition of a wind tunnel "nozzle," which describes it as "the contracting parts of an open-jet wind tunnel upstream of the working section." It may, of course, be argued that such a definition, valid as it is for open-jet subsonic tunnels, may serve to enlighten the younger generation of aeronautical engineers who think of a nozzle primarily as the part of a supersonic tunnel in which the flow is accelerated from a subsonic to a supersonic speed.

These comments may appear to bear the stamp of pedantry, and it must be confessed that the writer has been deliberately critical in his review of the Glossary because its Foreword and, indeed, its Title suggest a precision worthy of the British Standards Institution. If, on the other hand, we are prepared to regard the Glossary as a descriptive collection of terms with the purpose of elucidating, rather than of guiding, the vocabulary of aeronautics, then the Glossary will undeniably be a useful document.

SOURCE BOOK ON ATOMIC ENERGY. S. Glasstone. Macmillan Co. Ltd. London. 1950. 546 pp. Illustrated. Index. 24s. net.

This book is a notable addition to the literature on atomic energy and it is written in the clear style which those familiar with his books on physical chemistry have come to associate with Dr. Glasstone's writings. The volume has been sponsored by the United States Atomic Energy Commission with the purpose of providing a comprehensive and reliable source book on atomic energy for scientific writers and editors, and this requirement has undoubtedly been satisfied. Moreover the author has succeeded in providing a readable account of the subject which can be understood and appreciated by a sixth-science schoolboy. The book is well produced and its readability is considerably assisted by the adoption of two columns per page while the numbering of all paragraphs, illustrations and equations facilitates reference. There are eighteen chapters in all, starting with the foundations of the atomic theory and followed by considerations of energy and radiation, radioactivity and its measurement, nuclear radiations, isotopes, particle accelerators, the neutron, nuclear fission and nuclear energy reactors (or piles), cosmic rays and finally the increasingly important subjects of radiation protection and health physics.

The impact of atomic physics on everyday social and industrial problems has particular emphasis in Chapter XVI which deals with radioactive isotopes. The use of these isotopes in medicine, photosynthesis, the elucidation of mechanical frictional problems, metallurgy, and so on, are very carefully described. As regards the future possibilities of atomic energy from the economic standpoint, Dr. Glasstone suggests it is safe to assert that ultimately there will be little difference in cost between electricity produced from fission energy or from other sources of power.

This book should find a place on the shelves of all scientific reference libraries and its moderate price should tempt many private individuals to possess their own copies.

FIFTY YEARS FLY PAST. Geoffrey Dorman. Forbes Robertson Ltd. London. 1951. 346 pp. Illustrated. Index. 15s. net.

Books on the lines of this latest work by Geoffrey Dorman have appeared at irregular intervals ever since aviation became sufficiently long-established to have a history, as well as what almost amounts to a folk-lore, of its own. These informal histories have given popular accounts of the development of aviation while going into sufficient detail to emphasise the highlights of the story. At the same time, a personal account of the more interesting events which the writer usually witnessed himself provide their main theme.

Mr. Dorman has done rather better than his predecessors in the same field. Not only is his historical canvas larger and more comprehensive, but he has achieved some continuity in his story. This, helped by a useful index, should make "Fifty Years Fly Past" valuable for reference while retaining its primary interest for the casual reader. The lists of record holders and trophy winners are particularly complete and bring together a lot of historical information not previously available in one volume.

With all its good features this book will be widely read and it is therefore unfortunate that, almost inevitably, it contains a few historical inaccuracies. For example, Mr. Dorman perpetuates certain common misconceptions on the meaning of the aeroplane type-letters used by the Royal Aircraft Factory to name aeroplanes designed at Farnborough before 1918. S.E. never stood for "Sopwith Experimental" nor B.E. for "Biplane Experimental." There is ample documentary evidence that the original meanings of the various abbreviations were as follows:—

B.E. Bleriot Experimental (Tractor aeroplanes)
F.E. Farman Experimental (Pusher aeroplanes)
S.E. Santos Dumont Experimental ("Canard" aeroplanes)
T.E. Tatin Experimental (Aeroplanes with propeller behind the tail unit)

B.S. Bleriot Scout
R.E. Reconnaissance Experimental
N.E. Night Experimental
A.E. Armoured Experimental
} Functional designations

S.E. came to mean "Scout Experimental," after the "tail-first" S.E.1, when applied to the S.E.2 (originally B.S.2), S.E.4, 5 and 6 tractor biplanes. There does, however, still seem to be some doubt about the origin of two of the lesser-known Farnborough designations. C.E. may have stood for "Coastal Experimental" or for "Curtiss Experimental" (Curtis being the originator of the pusher flying-boat layout) while the meaning of the initials R.A.M., applied to two of the last Factory designs, remains obscure.

Part of the chapter on airships is misleading. Germany is given most of the credit for initial lighter-than-air development. Actually, the majority of early work on airships was done in France in the nineteenth century. Only after Zeppelin achieved success early in the present century did Germany establish a lead in rigid airship development that she maintained until these unique vehicles passed out of use. While the Germans concentrated on rigid airships, the French continued to set the pace in non-rigid and semi-rigid development until the 1914-18 War. Their Lebaudy designs—which were quite successful semi-rigids produced between 1902 and 1911—are considered by Mr. Dorman to have been the first successful airships. He overlooks the work of Giffard (1852), Dupuy de Lôme (1872), Haenlein (1872), Tissandier (1883) and Renard and Krebs (1884) who, among others, have prior claims.

Mr. Dorman has obviously put a lot of work into this book. The result, although badly printed, is a tale that everybody in aviation will enjoy reading. Their pleasure will be only slightly qualified by such idiosyncrasies of the author as his endlessly repeated references to "prancing-piston engines" and the "Dollar Princess." They will probably also feel that a more balanced selection of photographs than the 34 chosen could have been used as illustrations to amplify what is otherwise such a colourful panorama of the first fifty years of mechanical flight.

MIRACLE AT KITTY HAWK. Edited by Fred C. Kelly. Farrar, Straus & Young. New York. 1951. 482 pp. Illustrated. Index. $6.00 net.

As editor of this new book on the Wright brothers, Fred C. Kelly supplements his original biography with some six hundred letters chosen from thirty thousand manuscripts deposited in the Library of Congress by the executors of the late Orville Wright. Although members of the Royal Aeronautical Society would prefer a more technical selection, or alternatively the general reader might be helped by fuller interpolation of background details, the "Miracle at Kitty Hawk" nevertheless is surprisingly successful in producing the effect of an autobiography. From it emerges the portrait of two outstanding men, complimentary to one another, modest, frank and good-natured but essentially clear thinking, persevering and self-reliant.

Much of the character of the brothers is revealed in light-hearted letters to their sister Katherine and in personal letters to one another or to their friend, George Spratt, but it is those exchanged with the elderly Octave Chanute on technical and business progress that afford the main thread of continuity through the story.

Warm though their friendship is with Chanute and appreciative though they are of his advice, the letters of Wilbur in the course of ten years show increasing restraint, as though the brothers feel that their old friend is apt to be dangerously indiscreet. Ultimately there is revealed an unhappy divergence of view on the basic patents of the Wright system of control, and although both sides made overtures for conciliation, the death of Chanute intervened before the old friendship could be resumed.

Of outstanding historic interest are those letters written towards the end of 1903. Aware of impending trials with the rival Langley machine, the brothers

refused to hurry their own preparations, confident that they alone had the secret of control and that the conquest of the air for the first time with a power machine inevitably must be theirs. Every step made in perfecting power plant and winged structure had been a scientific development with never a blind shot in the dark. Wilbur wrote: "There is now no question of final success. The strength of the machine is all right, the trouble in the front rudder being easily remedied. We anticipate no further trouble in landings. Will probably have made another trial before you receive this unless weather is unfavourable."

A day later and the epic flight had been achieved. There was no excitement about it, nor self-congratulation; they had done only what they expected to do. Laconically, Orville telegraphed to his father: "Success four flights Thursday morning all against twenty-one-mile wind started from level with engine power alone average speed through air 31 miles longest 59 seconds inform Press, home Christmas"—but the Press did not think a flight of less than a minute worth reporting. In fact, the world-wide importance of the Wrights' achievement is not always realised even today. The publishers' "blurb" on the cover of "Miracle at Kitty Hawk" modestly states: "This volume must be considered as an important addition to American history." It would appear that the British are not the only people who are insular!

AIRCRAFT DESIGN DATA BOOK. Leslie E. Neville. McGraw-Hill Book Co. Inc. New York and London. 1951. 534 pp. Illustrated. 85s. net.

Any book relating to aircraft design is in itself a rarity. This may be because those engaged in aircraft design are always thinking ahead and are not vitally interested in recording what has been done. If this is so, anyone expecting data on up-to-the-minute aircraft will be disappointed in this book. The author's object is contained in a note in the introduction, "Design details of older aircraft frequently furnish solutions to design problems in current work." Consequently, although details are given of many aircraft, the most modern types covered are several years old, but this is understandable as design features of new aircraft are not readily released by constructors.

The book is pictorial in treatment and is a collection of sketches and photographs of aircraft and aircraft parts with sufficient text to describe the parts illustrated, a method used by many engineers and teachers who retain magazine material for reference.

The first part of the volume covers the general design characteristics of a number of single-, twin- and multi-engined types of aircraft, in the main of American, British and German origin. It is refreshing to read an American book and learn that the idea of presenting technical aeronautical information in three-dimensional form did not originate in the U.S.A., but in the aviation journals of England and France.

The bulk of the book is given over to sections dealing with the structural details of the major components of the aircraft. Design details are given of a number of wings, including ailerons and flaps, fuselages, tail units, landing gears and control systems. These sections are well presented, particularly the one on control systems.

Other sections relating to fixed-wing aircraft are devoted to fuel and oil systems, power plant installations and miscellaneous design details. In the power plant installation section no details are given of jet engines and the miscellaneous section is mainly confined to gun installations.

The remaining sections deal with rotating wing aircraft and turbine engines, but the information given is comparatively brief and should be reasonably well known to people engaged on this class of work.

This book is a useful compendium for most designers, or students of design; it is expensive but contains a great deal of information in one volume.

THE PRINCIPLES OF AIR NAVIGATION. Wing Commander E. W. Anderson. Methuen. 264 pp. Illustrated. Index. 25s. net.

This may well become a standard book of reference for the practical air navigator; the subject is treated exhaustively. Perhaps the best quality of this book lies in its approach and attitude of mind, above all in its treatment of errors. The subject of errors is introduced at the beginning of the book and is constantly recurring and being discussed in an extremely sound way. As one consequence "guestimation" has an important place in the book.

Mathematics are reduced to the minimum essential and there is constant use of the phrase "it can be shown that"; there need be no quarrel with this. It is only perhaps on the introductory mathematical chapter that the writer would like to comment. This chapter is written in the form of a continuous discourse but it is too condensed to be followed clearly. On page one a proof is given that $(A-B)(A+B)=A^2-B^2$; on page 8 a mechanical integrator is described too briefly to be clearly understood, and by page 11 one has reached the problem of astro-shots taken from tilted platforms. Instead of attempting a potted course of the relevant mathematics in ten pages, it might have been better merely to give a list of the mathematical facts that would be needed, either at a single place in the book or where the need arose.

Homely analogies of complex physical phenomena have been used effectively. A single exception was that of water flowing down a pipe as an analogy of a wave guide; would not the speaking tube have been a better, particularly as it was a familiar form of aircraft intercomm. (Gosport) until the beginning of the Second World War.

The relative emphasis given to the different aspects of the subject is very satisfactory. A desire for more about wind structure and about the construction of bubble horizons may have been only a personal one. Not unreasonably the descriptions of the various radio and radar systems consist of only brief introductions; for a full understanding of these systems the reader must look elsewhere.

A final word on error, and in particular on the subject of "most probable position" which is well treated on page 244. Recent theories of "information" lend clarity and explain the soundness of these matters. "Quantity of information" has been defined in a useful way. In the present context "the quantity of information" contained in a statement as to one's position on the surface of the earth is inversely proportional to the probable error of the statement. Zero error implies infinite information and neither occur in Nature. Most probable position is an intermediate position between other positions found in different ways each weighted according to the quantity of contained information. The author should not have deserted this viewpoint in his final paragraph 63. "The experienced airman" contains a vast amount of stored information which may alter the relative weighting of positions found in different ways. This does not mean that "he can afford to laugh at most probable positions." Through Information Theory the pure mathematician and the experienced airman are discovering a common viewpoint.

CREEP OF METALS. L. Rotherham. The Institute of Physics. London. 1951. 80 pp. Illustrated. Index. 15s. net.

Our foreign friends, employing a freedom of expression more usual between relatives, have on occasion told us that the British Empire has been built on the basis of brute force and adjectival ignorance. Be this as it may, it can be seriously advanced that many of the triumphs of both the civil and the mechanical engineer, have had an identical foundation. Wrought iron bridges in different parts of the world are standing today, which, because they came into being more than a century ago, must have been designed by engineers who had never heard of that far from blessed word, fatigue. Similarly heat engines, created by men completely ignorant of the complex phenomenon of creep, have had long and useful lives and have

generally been replaced, not because of mechanical failure, but because advances in applied thermo-dynamics have rendered them conspicuous by their inefficiency.

Mr. L. Rotherham, determined to show the engineer a skeleton in his cupboard of which he has hitherto been largely ignorant, now gives use an excellent dissertation on the subject of creep. He does this as a physicist and, in the main, does it very well indeed (if one overlooks an almost invariable fault of technical books, the inadequacy of his index). He has lucidity of expression and a deep knowledge of his subject. If he is to be criticised at all, this can be only on two grounds. He does not take quite sufficient account of his engineering and metallurgical readers knowing so much less mathematics than himself. Further, he makes no concession at all to the complete ignorance of commercial alloys of ultra modern physics. With regard to transient creep, he discusses the implications of theories of Becker and Orowan.

He doubtfully deduces therefrom the equation:—

$$dy/dt = \text{constant} \times \exp\left[\{ -[\tau_0 + S(\gamma) - q\tau]^2 V \} / \{ 2GkT \} \right]$$

This, he then damns with faint praise, but he would have done better to have left it out. Few of his readers will appreciate its significance, while the reviewer, a metallurgist of many years of experience, can assure him that no single crystal, let alone a polycrystalline, random orientated, inclusion containing aggregate would understand what was expected of it. The mental disequilibrium of the centipede lying distracted in the ditch, would be as nothing to that of this most unfortunate piece of metal.

NON-METALLIC MINERALS. R. B. Ladoo and W. M. Myers. Second edition. McGraw-Hill Book Co. Inc. New York. 1951. 605 pp. Illustrated. Index. $10.00 net (85s.).

Non-metallic minerals are defined as those which cannot be classified as fuels or as metallic ores. They form a miscellaneous group of substances having an exceedingly wide range of applications. Details of the occurrence, winning, benefication and utilisation of many of these minerals are dispersed throughout a very scattered, and often rather inaccessible literature.

The chief value of this book lies in the fact that information appertaining to such minerals is presented in a readily accessible form. Although described as the second edition of a book published under the same title in 1925, such sweeping changes and additions have had to be made during the revision that this edition is virtually a new book.

The authors have described in greater detail those minerals having a particularly meagre and scattered literature, whereas minerals, such as clays, about which information is more readily available, have been treated less fully. The result is a remarkably compact volume. The information is up-to-date, and data on the specification and testing of the minerals is given. A useful bibliography is provided.

While some minerals, such as anhydrite, bauxite, chromite, and so on, are considered individually, others are grouped under headings such as abrasives, fillers and absorbents. These headings are arranged alphabetically. This arbitrary method of presentation often leaves one in doubt as to where to look for a particular mineral if this is not listed under a separate heading. The index goes a long way towards alleviating this difficulty, but could be made much more comprehensive with regard to mineral utlisation, processing technology, and so on.

From the point of view of the British reader there is a serious drawback. The book is intended for the American user. Consequently, much of the data refers specifically to the United States market, and occurrences of minerals outside the United States are considered only in so far as they affect the American producer or consumer. This detracts from the usefulness of the book to the non-American. Nevertheless, the information given on such topics as the technology of mineral extraction and benefication at present in use in the United States, entitles the book to a place on the shelves of all those interested in non-metallic minerals.

THE INELASTIC BEHAVIOR OF ENGINEERING MATERIALS AND STRUCTURES. Alfred M. Freudenthal. John Wiley & Sons Inc. New York. 1950. 587 pp. Figures. $7.50 net (60s.).

After a short introduction, this book falls into three main parts, dealing respectively with "the Structural Aspects of Mechanical Behaviour," "the Mechanics of Inelastic Deformation" and "Application of the Mechanics of Inelastic Behaviour." The object of this division is to present a complete picture of the mechanical behaviour of materials strained beyond the elastic range, combining the physical and engineering approaches. Of necessity, therefore, it must attempt to present current views in the fields of physics, physical metallurgy, chemistry (to a limited extent) and engineering. This is a wide field for a single author to cover in an authoritative manner, but the quality of the book must be assessed on the relative success with which it is done.

Considering the physical point of view first, it must be confessed that the first two chapters are much the same as has been written in a number of earlier books on metal physics. This is not unexpected and is only to be construed as criticism in that the emphasis might have been placed rather differently. For example it might be questioned whether the space given to Bohr's model of the atom and similar basically physical subjects in Chapter I might not have been spent on a lengthier development of the sections dealing with the effects of departure from a perfect crystal lattice, and of metallographic structures on the inelastic properties.

The second and longest part of the book shows more clearly the approach of the engineer but this section contains a number of interesting descriptive interludes. The section on creep and relaxation seems a particularly clear description of the phenomena involved, while those on work hardening and fracture contain some thought-provoking suggestions, not all of which are orthodox.

Finally, the earlier ideas are developed and applied to some particular cases and the book concludes with a chapter on the significance of mechanical testing which is most interesting and useful.

The book contains much stimulating and interesting material but it is not uniformly successful in achieving its objects. In part this is because the aim is high and in part because the method of presentation with alternations of analytical and descriptive matter is not always conducive to easy reading. Nevertheless, the author succeeds in impressing his own point of view on the material he has accumulated and the result is a volume which is well worth reading, although the reader may find himself differing from the author on many points. The engineer using the book as a guide to information outside his usual field should regard it as a starting point and be inclined to consult some of the many references which are given throughout the book.

CLOUD PHYSICS. D. W. Perrie. University of Toronto Press. Canada. 1950. Geoffrey Cumberlege, Oxford University Press. London. 119 pp. Illustrated. Index. $4.50. 32s.

A book with this title will arouse wide interest as there have been important advances in recent years in knowledge of Cloud Physics and a comprehensive and critical survey would be useful. It is a disappointment to find that the book under review does not live up to its title, as it is more concerned with the observation of clouds than with their physical make-up. The wrong note is struck at the very start. The opening chapter consists of a bald statement of the classification of clouds by their heights which, however useful and convenient, is unsatisfactory physically, as no distinction is made between ice clouds and water clouds. This is no sort of introduction to the nominal subject of the book. As a book for the lay reader on the subject of clouds there is much of interest, and the collection of photographs of different types of cloud is excellent.

On the subject of Cloud Physics the information given is not up-to-date, and the complete absence of critical comment suggests that the subject, really, is outside

the author's scope. The absence of critical comment is particularly conspicuous in the discussion of the formation of rain from clouds at temperatures above freezing. The reader is left to swallow a theory which postulates that adjacent droplets in the clouds are at different temperatures. It can be shown by calculation that the growth of the drop by condensation, as it attains equilibrium, is insignificant.

There are important omissions. There is no mention of the work both at Oxford and in America on nuclei of crystallisation, or of Langmuir's theory of rain-making by collision of droplets. The work of Lewis and others of the N.A.C.A. on icing clouds has escaped the author's attention. There should be more on the subject of gusts and atmospheric turbulence, as well as on the electrical and optical phenomena associated with clouds. Various forms which may be taken by ice in the atmosphere should be described.

Nuclei of sublimation and condensation are treated together instead of separately which makes it difficult to appreciate their proper significance. While we do not know exactly what are the nuclei of condensation, the important fact is that they are always present in sufficient numbers for clouds to form without appreciable supersaturation. Nuclei of sublimation have a tremendous significance which is not emphasised. Effectively, they cause a cloud, or a part of it, to freeze and, if circumstances are suitable, initiate rain. In the absence of nuclei much greater cooling of the cloud would be necessary for rain to occur, unless the concentration of water was high enough for rain drops to be formed by the process of collision. The fact that conditions of icing have been reported at temperatures down to about $-40°$ C. suggest that the nuclei of crystallisation are variable in efficiency. This is confirmed by experiments both in this country and in America. The whole problem of the freezing of clouds has a direct bearing on the problems of protecting aircraft against ice and of predicting conditions of icing.

Much of the information in the Glossary should be imparted more fully in the main text. The stability of the atmosphere, for instance, should be treated fully and should include a discussion of the energy of a mass of unstable air and its dissipation by mixing and other processes.

THE GAS TURBINE MANUAL. R. J. Welsh and G. Waller. Temple Press Ltd. 1951. 243 pp. Illustrated. Index. Appendix. 25s. net.

In this book dealing with the gas turbine engine in its industrial, marine and land transport forms, an attempt is made to cover the thermodynamics, design theory and practice, the problems and the factors bearing on this type of power plant when considered for such applications. To this are added descriptions and data on designs of gas turbine plant either built or now being built for industrial, marine and transport usage. To compass this field within a slim volume of some 250 pages has resulted in many of the subjects covered being given but superficial attention, a feature that will not commend itself to the more serious reader.

In layout, the first nine chapters deal with first principles, thermodynamics of performance, and design theory and practice, including chapters on early history and metallurgy. It is in these chapters that the superficial treatment is most noticeable. The chapters on first principles and thermodynamics contain but the most elementary and, at times, over-simplified analyses, continuity being interrupted by digressions into topics that would have been far better left until a clear description of the fundamental theory had been set down. In those sections of the book dealing with component design theory and practice, there is but little attempt to come to grips with the basic principles of design and in avoiding the use of mathematics the authors offer a purely descriptive treatment. Although attempts are made to show the inter-action of aero-thermodynamic and mechanical considerations in heat exchangers and the like, such important questions are hardly touched on in the chapters dealing with compressors and turbines.

Following the first nine chapters are a further five dealing with the applications of the gas turbine engine, although for the purpose of this review the two-page chapter on the aircraft application may be disregarded. Of these chapters, perhaps those dealing with the locomotive and power station applications are the best, for here there is a fair description of the problems and the advantages and disadvantages of the various possible forms of gas turbine engine in relation to other prime movers. The chapter on the marine application is rather scanty and inclined to convey a too optimistic picture of the possibilities of the gas turbine engine in this application.

The remainder of the book, about one third of the whole, is devoted to descriptions and data on gas turbine plants for all applications except aircraft. This section is as comprehensive as could be expected and covers all the non-aircraft gas turbine plants either built or at present being built. To have such complete data under one cover undoubtedly lends the book merit and makes it of use to the experienced gas turbine engineer.

For the student and engineers generally, the book can be regarded as no more than a very general qualitative introduction to the technicalities of the gas turbine engine; for the proper appreciation and understanding of this they will need to turn to more specialised works which do not avoid mathematical language.

THE MATHEMATICAL THEORY OF PLASTICITY. R. Hill. The Clarendon Press. Oxford. 1951. 356 pp. 90 figures. 35s. net.

The theory of plasticity bears some resemblance to the game of bridge; it is played according to laws which are immutable except when they are changed. By comparison the rigid discipline of elasticity seems as dull as the game of whist. Still, it is perhaps pertinent to recall that the major coups of the bridge-table were all first achieved at the older game.

Plasticity is indeed a dull pudding and Dr. Hill is to be congratulated on almost convincing us that the heavy suet is digestible and even, at times, enjoyable. Liberally garnished with notation, mostly having the fashionable tensor flavour, the first few mouthfuls go down quite pleasantly, and only when the stodgier centre portion is attacked does one realise that even the attractive crust is not agreeing with one too well.

Why should good wholesome pudding like this disagree? It is guaranteed entirely free from Hencky and to contain nothing but the purest essence of Levy-Mises-Reuss; it is mixed incrementally at every stage, and the numerical integrator has been constantly in use to keep the heavy mixture on the stir. Do we perhaps regret the evanescent, elastic glory of a meringue or the brisk, brittle snap of a gingernut?

The first three chapters, the first mainly an historical survey, the second on the basic principles and the third on fundamental theorems, afford the foundation for the whole work. Yet even thus early indications are not lacking that the completed castle may leave us somewhat in the air. "This is the simplest and most attractive hypothesis conceivable for the ideal plastic body, and it will accordingly be used in all subsequent applications. (Paragraph) It now remains . . . . justified by its simplicity and approximate agreement with observation. (Paragraph) We now state the hypothesis mathematically. Let $d\varepsilon_{ij}$ . . . ." This single quotation reflects the style of the whole book; the author is happiest when he can let the good dog Tensor off the lead, and if actual materials do not come to heel, should he worry?

The criticism is of course captious, the foundation of elasticity is in that sense no sounder, but on the other hand is the author's promise of simplicity really fulfilled? Does $d\varepsilon_{ij}^{e}=\frac{d\sigma_{ij}'}{2G}+(1-2\nu)\delta_{ij}\frac{d\sigma}{E}$ readily convey the basis of elasticity? and is not $\sigma\,\dot{\bar{\sigma}}$ almost as irritating to the reader as it must have been to the printer (who by the way has done an excellent job)? Perhaps in a second edition Appendix

I might be promoted to a footnote somewhere in Chapter II in order to give the reader an earnest that the tensor notation can pay its way. In the two chapters on plastic-elastic problems the reference back has to be moved far too frequently, and here as throughout the book the writing seems very much better than the reading. The author makes it abundantly clear that he knows what he is at, but too often he keeps it dark from the reader; for instance, the derivation of formula (10) on page 100.

Aeronautical pawns who may attain the sixth square will probably note with astonishment that a phenomenon having much in common with supersonic flow no longer holds for them any element of shock; rather should they heave sighs of relief. This feeling should support them onwards almost to the end of the tenth chapter, and thereafter topics miscellaneous and plastic anisotropy are clearly matters to be left to the priesthood; the laity need not fear to be catechised on those. To prove that he did indeed survive so far the reviewer renders the usual earnest of two misprints, *D* for *B* on page 165 and an *r* omitted from page 268; he regrets that he could find no more.

Finally one may turn back once more to the earlier pages to savour again some of the few quite cryptic passages . . . . "Baranski, who extended bars of brass and mild steel under approximate conditions of plane strain (the corresponding analysis for tension is obtained by changing the sign of *Y* in the above equations)." Good man, Baranski!

A fair book on a dark subject.

FLUID MECHANICS. V. L. Streeter. McGraw-Hill Book Co. Inc. New York. 1951. 366 pp. Illustrated. Index. $5.00 net. 42s. 6d.

In recent years the gulf between the empirical subject of hydraulics and the theoretical one of hydrodynamics has narrowed, and a number of text books have appeared which attempt to cover both fundamental principles of fluid mechanics and also practical applications arising in engineering. This book should not be confused with the same author's earlier book "Fluid Dynamics," which is mainly concerned with hydrodynamics from a detailed theoretical standpoint.

The introductory chapters deal with fluid statics and the basic concepts of fluid flow. A chapter is devoted to the action of fluid jets and hydraulic turbo-machinery, and is followed by a general one on laminar flow. Flow measurement comes next, followed by a long discussion on the important hydraulic topics of flow in pipes and open channels. The next chapter is concerned with flow round immersed bodies, covering both perfect fluid flow, and more briefly, the boundary layer and drag. Finally there is a short chapter on oil hydraulic systems.

There is little in this list of contents which appears to be of specific interest to the aeronautical engineer, but this in itself would be no fault in a fundamental text book, were it not that the treatment of many topics does not appear to have been influenced by the achievements of aerodynamics. For example, the aerofoil only warrants a single lift and drag curve, with no reference to, say, the pressure distribution round it; consequently, in the brief section on the propeller there is no mention of blade-element theory. This in turn reacts on the author's analysis of hydraulic propeller turbines and pumps, the designs of which are today based on aerofoil theory, other than on the simple treatment given here. Another example is that of model testing; a brief paragraph mentions the use of hydraulic models, but there is no reference to wind-tunnel testing from which a great deal of knowledge of Reynolds number and boundary layer effects has been learnt. Jet propulsion and rockets are covered in a few paragraphs. The final chapter on oil hydraulic systems contains very little fluid mechanics, being largely devoted to descriptions of various manufacturers' pumps and valve systems.

It is only in Chapter IX, when discussing potential flow that the author seems to be at home, and it is here that the standard of this book approaches that of the earlier "Fluid Dynamics." The latter half of this chapter dealing with real fluid and

drag falls off, however, and thus the one page dealing with the effect of compressibility is inaccurate. Among other things, the conical envelope of the spherical sound waves in supersonic flow, the Mach cone, is called a shock wave.

There are a number of other minor criticisms, but the main criticism in the reviewer's opinion is the omission of a fundamental discussion of dimensional analysis and units. This omission mars the treatment of nearly every topic, since the student will not appreciate the underlying unity of the non-dimensional parameters such as Reynolds number, Froude number, Mach number, specific speed of turbines and pumps, friction factor in pipe flow and lift and drag coefficients. Thus, as an example, the propeller is discussed without mention of thrust and torque coefficients or advance ratios. In fact, the author sows the seeds of doubt when he describes the friction factor in pipes, f, as ". . . the dimensional factor required to make the equation yield the correct answer." That is precisely what the uninitiated feel is the "wangle" of these coefficients, whereas they are the elegant result of one of the most simple yet powerful analytical tools of fluid mechanics.

Among the problems at the end of each chapter, the author has included a number of what he describes as "objective problems of the multiple-choice type." Thus, selecting at random, "The shear stress in a fluid flowing between two fixed parallel plates (*a*) is constant over the cross-section (*b*) is zero at the plates and increases linearly to the mid-point (*c*) . . . . (*d*) . . . . (*e*) none of these answers." In spite of Professor Streeter's assurance that he has used this type of question with success, this reviewer is a little worried that it might encourage the "quiz" mentality rather than learning to think and to approach a problem analytically.

On the whole, this book covers a wide field of fluid mechanics and contains a great deal of useful information. This reviewer, however, must confess to being disappointed in the high hopes he had of it, based on the favourable impression made on him by Professor Streeter's earlier "Fluid Dynamics."

THERMODYNAMICS OF FLUID FLOW. Newman A. Hall. Prentice-Hall Inc. New York. 1951. 278 pp. Illustrated. Appendix. Index. $7.35 net.

The estimation of the performance of propulsive and other systems involving fluid flow and heat addition is usually made on the basis of one-dimensional steady flow. For both incompressible and compressible flow it is necessary to find a solution to the equations of conservation of mass, momentum and energy, and the only difficulty, once the geometry and physical state of the system are known, is the allowance for friction and other losses in the system. Since in general only the overall performance is required the latter may be included in the form of averaged empirical coefficients. In certain cases a closed solution is available but in others a solution by trial and error or by graphical methods is necessary.

In this book the problem is investigated in a clear and concise manner. The analysis is simple and the final equations are presented in a form suitable for easy solution of typical practical problems. It should form a useful reference guide for engineers engaged on the performance of fluid flow and heat addition problems. Many useful tables are included in appendices and the use of these is illustrated in the many worked and unworked examples which are distributed throughout the text.

The subject matter in this book is arranged as follows. After introducing the necessary units, dimensions and the state properties of fluids, the author devotes a chapter to the problem of friction in pipes including the theoretical and empirical laws for the estimation of fluid viscosity, friction as affected by surface roughness, and standard flow losses. The equations of continuity, momentum and energy are derived for one-dimensional steady flow and are simplified for the special cases of the flow of incompressible fluids and perfect gases. Solutions to these equations are given in succeeding chapters for flow under constant-area adiabatic conditions, varying-area adiabatic conditions, and flow with normal shock waves. A chapter on flow measurement and flow control is followed by an investigation into problems involving diabatic flow (a flow with extensive heating or cooling). Finally the

performance of propulsive systems is described by using the ideas developed in the previous chapters.

Statements regarding the description or physical processes could have been made with greater clarity. For example, in the formulation of the energy equation the terms involving frictional work could have been included. Although the latter terms appear equally on both sides of the energy equation, it is felt that this is no justification for their omission. Further, on page 29, when explaining the effect of surface roughness the author refers to the laminar sub-layer as unstable, when in fact its stability cannot be in doubt. On page 182 the notation relating to equation (12.1) is not stated but has to be inferred. British readers will feel that the use of the pound mass and the gravitational conversion factor throughout is a retrograde step.

DISPLACEMENT PUMPS AND MOTORS. R. Hadekel. Pitman. London. 1951. 170 pp. 177 diagrams. Index. 25s. net.

Few books devoted entirely to displacement machines have been published; possibly because of this fact, the author has treated the subject in its widest form, and has dealt with the various forms of the fundamental mechanisms upon which all displacement units are based. This is perhaps the most logical treatment, considering the lack of literature on the subject, as it prepares the way for other books dealing with the design and application of equipment for the various specialised duties.

The first nine chapters are devoted to a carefully classified presentation of displacement elements, well illustrated by clear diagrams and with notes on the basic design calculations of the more familiar types. Some of the diagrams show mechanisms which appear to have no practical value, but their inclusion is justifiable for the sake of completeness, and because they maintain the logical development of the classification. There are in this section several problems relating to lubrication which are posed rather than answered. This is inevitable, because these problems can only be solved when all the operating conditions are known. Even so, many people will disagree with the author's over-simplified analysis of the stability of clearances between ported surfaces, as it omits the effects of rotation and local changes of clearance on the interface pressure gradient.

On page 6, the constant for the conversion of hydraulic output to horsepower is given as 0.007. This should read 0.0007.

In the subsequent chapters which deal with constructional problems, general problems, variable flow machines and displacement machines in practice, the deliberately wide scope of the book has limited the discussion to the more general aspects of the subject. Rotational cyclic variations are fully discussed, but the chapter headed "Variable Displacement Machines" outlines only what may be termed the geometry of displacement variation, and does not mention the methods of automatic control or their characteristics.

The main value of this book is that it presents a collection of basic information on displacement units in one volume for the first time. It cannot be claimed that it introduces any new thoughts on the subject, although few readers will fail to derive some benefit from it.

One serious criticism—there is only a single reference to other published data.

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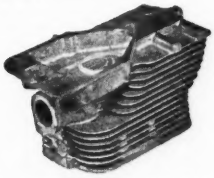

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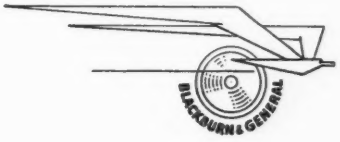

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